NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

USING AGENT-BASED MODELING TO EXAMINE THE LOGISTICAL CHAIN OF THE SEABASE

by

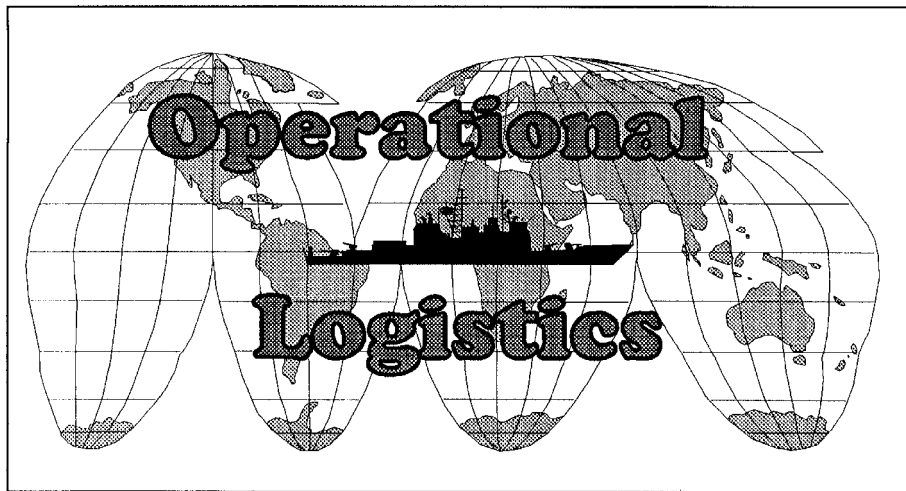Rebecca M. Milton

March 2004

Thesis Advisor:	Susan M. Sanchez
Second Reader:	Lloyd P. Brown

Approved for public release; distribution is unlimited

Amateurs discuss strategy,
Professionals study logistics!

REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE March 2004	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE: Using Agent-Based Modeling to Examine the Logistical Chain of the Seabase			5. FUNDING NUMBERS
6. AUTHOR(S) Milton, Rebecca M.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

    This thesis examines a 2015 Marine Expeditionary Brigade scheme of maneuver as the baseline scenario for a commercial logistics support software program called SEAWAY. Modifications to this scenario are conducted using a designed experiment in order to explore how the plan characteristics relate to eleven specified input factors. Multiple regression analysis is used to fit models to the resulting data for three different measures of performance: Total Aircraft Sorties, Total Aircraft Sortie Time and Total Aircraft Tons. The results suggest the plan performance is predicted well by a small subset of the factors and their interactions.

    One implication of this work is a better understanding of which factors are key determinants of the plan characteristics for variations on this specific base scenario. By using these fitted models, the number of SEAWAY runs needed to identify acceptable plans should decrease dramatically. The approach in this thesis provides a blueprint for similar analyses of other scenarios by demonstrating how information gained from models fit during an exploration phase might allow the logistician to quickly determine factor settings that yield an acceptable plan once details of an operation become available. Finally, working with the SEAWAY developers provided them with some new insights.

14. SUBJECT TERMS Agent-based models, Seabasing, SEAWAY, Latin Hypercube (LHC) design, Scheme of Maneuver (SOM), Marine Expeditionary Brigade (MEB)			15. NUMBER OF PAGES 90
			16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

USING AGENT-BASED MODELING TO EXAMINE THE LOGISITICAL CHAIN OF THE SEABASE

Rebecca M. Milton
Lieutenant Commander, United States Navy
B.S., Norfolk State University, 1992

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
March 2004**

Author: Rebecca M. Milton

Approved by: Susan M. Sanchez
                Thesis Advisor

                Lloyd P. Brown
                Second Reader

                James N. Eagle
                Chairman, Department of Operations Research

iii

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This thesis examines a 2015 Marine Expeditionary Brigade scheme of maneuver as the baseline scenario for a commercial logistics support software program called SEAWAY. Modifications to this scenario are conducted using a designed experiment in order to explore how the plan characteristics relate to eleven specified input factors. Multiple regression analysis is used to fit models to the resulting data for three different measures of performance: Total Aircraft Sorties, Total Aircraft Sortie Time and Total Aircraft Tons. The results suggest the plan performance is predicted well by a small subset of the factors and their interactions.

One implication of this work is a better understanding of which factors are key determinants of the plan characteristics for variations on this specific base scenario. By using these fitted models, the number of SEAWAY runs needed to identify acceptable plans should decrease dramatically. The approach in this thesis provides a blueprint for similar analyses of other scenarios by demonstrating how information gained from models fit during an exploration phase might allow the logistician to quickly determine factor settings that yield an acceptable plan once details of an operation become available. Finally, working with the SEAWAY developers provided them with some new insights.

THIS PAGE INTENTIONALLY LEFT BLANK

THESIS DISCLAIMER

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government

The reader is to proceed with caution regarding the computer programs used in this research. The computer programs may not have been exercised for all cases of interest. While every effort was made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Seabasing is at the core of "Sea Power 21." It is about placing at sea capabilities critical to joint and coalition operations. By doing so, it minimizes the need to build up forces and supplies ashore, reduces their vulnerability, and enhances operational mobility.

SEAWAY is a maritime logistic decision-support system that assists in executing seabase operations and in providing visibility on all cargo items in theater. Designed to operate in the Windows NT environment, SEAWAY employs a number of expert agents that collaborate with users to provide the information necessary for realistic and timely logistic support. SEAWAY plans, coordinates, and controls the ship-to-objective delivery of supplies ashore. SEAWAY agents are able to automatically reason about current and simulated Seabasing conditions. Specifically, in a planning mode the agents function as intelligent tools that are able to assess the logistics supportability of schemes of maneuver or courses of action and develop delivery schedules within the constraints of limited transportation assets, environmental conditions, and the availability of supplies. This commercial software has been fielded out to the fleet so that logisticians will be able to use this decision-support tool locally.

The time required to develop a plan in SEAWAY varies, depending on the scenario characteristics and logistics requirements. If the plan is unacceptable (e.g., the required delivery schedule cannot be met), then the logistician may alter some of the requirements or resources, and rerun the software so SEAWAY can develop a new plan. However, this can be a time-consuming process and the logistician may have little information about how to alter the plan inputs in order to come up with an acceptable plan.

In this thesis, we examine a 2015 Marine Expeditionary Brigade scheme of maneuver as the baseline scenario. Modifications to this scenario are conducted using a an efficient experimental design in order to explore how the plan characteristics relate to eleven specified input factors. We then use multiple regression analysis to fit models to the resulting data for three different measures of performance: Total Aircraft Sorties,

Total Aircraft Sortie Time and Total Aircraft Tons. These results suggest that the plan performance can be predicted well by a small subset of the factors and their interactions.

One implication of this work is a better understanding of which factors are key determinants of the plan characteristics for variations on this specific base scenario. By using these fitted models, the number of runs of SEAWAY needed to identify acceptable plans should decrease dramatically. The approach in this thesis also provides a blueprint for similar analyses of other scenarios, by demonstrating how information gained from models fit during an exploration phase might allow the logistician to quickly determine factor settings that yield an acceptable plan once details of an operation become available. Finally, working with the SEAWAY developers has provided them with some new insights.

There are a few other areas where this thesis was beneficial. We were able to contribute to the developer's process improvement of the overall system for a fielded program. By becoming involved early in the fielding process, we were able to provide inputs on ways the program could be used more effectively in the field, i.e., expanding the input process to include batch processing and by introducing and developing a model in a pre-planning stage. Our analysis also provided insight into the factors contributing to the success or failure of the logistics chain of the seabase. Finally, we showed that a structured sound analysis contributed to a successful "back of the envelope" approach. All of these benefits ultimately contribute to this scenario being used as a template from which other seabase logistics scenarios can be analyzed.

Because seabasing operations will be increasingly important over the next decade, the need to effectively model and analyze seabasing scenarios is critical to determine best practices for conducting seabasing operations. It is clear that seabased logistics is a bold move toward a fully integrated warfighting capability that will take the military forces into the 21st century.

I. INTRODUCTION

Operation Iraqi Freedom (OIF) highlighted logistics support delivered over some of the longest lines of communication ever experienced by Marine forces…improving logistics effectiveness is an essential element of enabling seabasing capabilities of persistence, sustainment, and reconstitution at sea…30 year old mainframe-based systems…highlight a critical need to modernize Marine Corps logistics…requiring an integrated MAGTF approach focusing on modernization of logistics technology.

-General M. W. Hagee, USMC,

Commandant of the Marine Corps, February 2004

In this thesis, we examine how to support the logistics chain in a seabasing environment. To accomplish this, we must first understand the past, present, and future of seabasing logistics.

A. HISTORY OF SEABASING

"Seabasing has been a characteristic of navies since the first warships went to sea" (Nagy, 2002). During World War II, the geographic area of the Central Pacific proved to be a logistics challenge. At the time, forward logistics sites in support of forces abroad were scattered at established bases across the vast central Pacific. This forced logisticians to come up with out-of-the-ordinary locations for staging material, i.e., remote anchorages or lagoons. The Navy was forced to come up with an alternative method of establishing logistic chains. The organization in the U. S. Pacific that was tasked with overcoming this obstacle was the command Service Force Pacific. This organization was tasked to provide "the Navy's fast carrier task forces with the ability to conduct offensive operations against the Japanese" (Nagy 2002). Amphibious command ships like the AGC-3 USS Rocky Mount (Figure 1) were the "brains" behind the amphibious assault groups invading and assaulting island targets through out the western Pacific. This type of ship looked like a supply ship but was actually a front-line command post, coordinating the movements of men and material in the Pacific. When needed it also served as a refueling ship, a medical triage, and a brig. During WWII, the ability of these ships to plan successful amphibious landings freed up the troops at sea to

stand by to execute orders to be re-supplied at sea and be available for the next task. In a rudimentary sense, the "seabase" for the U.S. Pacific Fleet was born.

Figure 1.   AGC-3 USS Rocky Mount (From Ref: Rhea, 2004)

After World War II, the logistics community continued to face challenges as world events dictated the deployment of troops overseas. From the end of World War II to the present day, a variety of ships have been placed into service to address these logistics issues. Some examples include the fleet of submarine and destroyer tenders used by the Navy during the Cold War, and the fleet of Maritime Prepositioning Ships "established in the early 1980s to improve response time of delivery of needed equipment and supplies to a theater of operation" (Military Sealift Command (MSC), 2004). Military events in the past decade have proven the importance of the establishment of these fleets. During Operation Desert Storm, prepositioning squadrons loaded with 30,000 Marines and their equipment sailed to Saudi Arabia in response to the Iraqi invasion of Kuwait. "To date, a major portion of the nation's sea-basing capability resides in the forty ships of the MSC Afloat Prepositioning Force, which provides global prepositioning support to the Army, Navy, Air Force, Marine Corps, and Defense Logistics Agency" (Nagy, 2002). In Figure 2, the USNS GYSGT Fred W. Stockham (T-AK 3017) is one of 36 ships in the current Maritime Prepositioning Force (MPF). The ships are especially configured to transport supplies for the U.S. Marine Corps. They contain nearly everything needed for initial military operations, i.e., tanks, ammunition, food, water, fuel, spare parts, and engine oil (MSC, 2004).

Figure 2.   USNS GYSGT Fred W. Stockham (T-AK 3017) (From Ref: MSC, 2004)

B.   SEABASED LOGISTICS TODAY

Military forces abroad have had to be flexible and quick to respond with military force in areas far away from fixed bases, transportation hubs and logistics centers. Early stages of Operation Iraqi Freedom (OIF) indicated the need for a seabase to evade access limitations imposed by countries that refused to allow U.S. troops to invade from their soil. As the war in Afghanistan unfolded, seabasing did eventually play a role in Special Operations (SPECOPS) forces' routine engagements. The SPECOPS forces benefited from the presence of a seabase available just over-the-horizon, which gave them the ability to covertly conduct insertion, extraction, fire support, and sustainment operations. However, the ships that compose today's seabases are limited in their ability to operate independently of advanced logistics bases. Their limitations include lack of ability to carry sufficient material, capacity to assemble sizeable forces, ability to selectively offload logistics, and airlift capacity to sustain forces ashore. "While the Navy and Marine Corps have some seabasing capacity today, the services hope to apply new concepts and technologies to project a whole host of new capabilities from the sea" (Waterline, 2003).

C.   FUTURE OF SEABASING LOGISTICS

The events of September 11, 2001, tragically illustrate the associated threats the American people will face in the future. These threats include—but are not limited to—

weapons of mass destruction, conventional warfare, and widespread terrorism. These threats will pose difficult challenges to national security and future war fighting strategy and tactics. To counter this risk, our Navy and Marine Corps must expand its power of projection, strategic sealift, and forward presence in order to project its military power to deal with a wide range of worldwide contingencies. The Department of Defense's solution to this pending threat is the old but new concept of seabasing.

Seabasing is one of the three war fighting capabilities that make up "Sea Power 21" (Figure 3) and is at the core of the Chief of Naval Operation's (CNO) vision for the 21st century. By controlling the coastal waters, seabasing places capabilities critical to joint and coalition operations within striking distance of potential military conflicts. In turn, this minimizes the need to build up forces and supplies ashore, reduces their vulnerability, and enhances operational mobility.

Figure 3.   Sea Power 21 (From Ref: Clark, 2002)

In order to support this new vision, seabased logistics will maneuver with seabased forces to support sustained operations while in theater. By operating from

ships, the logistics base will maneuver with seabased forces and support continual operations while on station.

1. Operational Maneuver from the Sea

"Operational Maneuver from the Sea (OMFTS) is the Marine Corps' new warfare doctrine expected to be in place by 2010" (Military Analysis Network, 2003). At the root of the OMFTS concept is the idea that all logistics support will come from the sea instead of from a large, land-based forward deployed logistic supply center (Figure 4). The ability to move by the sea, deploy near the scene of a crisis, power projection, provide sustainment from the sea, and redeploy forces from the sea will fully exploit the operational advantage of naval forces as a means of avoiding engagements with enemy forces. "This new maritime force maximizes its protection by limiting its footprint and hence its vulnerabilities ashore" (Krulak 1999).
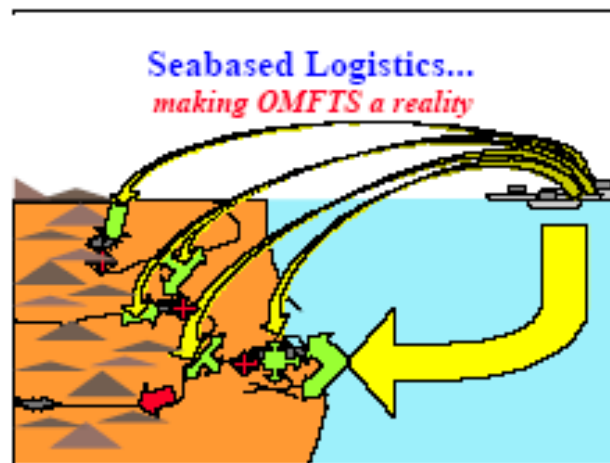
Figure 4.   Seabased Logistics (From Ref: Rhodes and Holder, 1998)

2. Ship-To-Objective-Maneuver

Ship-To-Objective-Maneuver (STOM) is one of the key implementing concepts to achieve the operational goals established by OMFTS. STOM defines the principles and tactics of forcible entry from the sea. Two key components of STOM are the tactical maneuver of forces and seabasing. STOM seeks to change the ship-to-shore movement to amphibious maneuver. The objective of STOM is to put combat units ashore—either

5

by air, surface or both means—in sufficient force to accomplish the mission (Bryan et al., 2002).

3. Action Group Reorganization

"In order for the Navy and Marine Corps to continue to operate effectively, they will organize, deploy, employ and sustain forces to conduct operations guided by the concepts of seabasing integrated with the family of Marine Corps concepts, Expeditionary Maneuver Warfare (EMW), OMFTS and STOM" (NOC 2003).

As the seabasing concept of operations evolves over the next decade, force requirements will develop to include strike forces such as carrier strike groups (CSGs) and surface action groups (SAGs) in order to maintain air superiority and support deep strike operations. Additionally, the implementation of expeditionary strike groups (ESGs) will be necessary to provide the initial point of entry for ground force operations. Seabasing requirements will call for a versatile force capable of supporting a Marine Air-Ground Task Force (MAGTF) from over 600 miles (681.81 nm) from the theater of operations. The seabase will be required to support an entire brigade in its numerous evolutions and be expected to support air operations involving tactical Joint Strike Fighter (JSF) aircraft, vertical takeoff and landing (VTOL) transports, as well as a variety of large transport and attack helicopters (NOC 2003).

Since the seabase will need to be versatile with cargo and ground forces, ship assets will require the use of Maritime Preposition Force (MPF) vessels. The MPF vessels' capabilities include air operations, vertical platforms such as the MV-22 tilt-rotor aircraft (Figure 5), a force of high-speed vessels (HSVs) and heavy lift Landing Craft Air Cushion (HL-LCACs) to connect the seabase with forces ashore and other theater assets. In addition, other support assets, such as combat logistics force ships (CLFs), will be required for delivering ground support equipment and supplies to support the seabase.

D. AGENT-BASED MODELS IN A SEABASE SCENARIO

In a seabase scenario, one specific area of military concern is the command and control of logistics operations. The complexity of these operations, along with the convergence of possible interactions outside of the control of the local commander, creates a situation not easily modeled. In particular, we initially began to explore agent-

based models (ABMs) currently being used for operational scenarios to see if they could be adapted to demonstrate logistics functions vs. operational functions. We found that replenishment functions were not easily depicted within the commonly-used ABMs. Since most agent-based models are rooted in "fire/kill/survive" functions, creative thinking is necessary in order to use these limited actions to simulate the concept of replenishment. For example, in a recent study of a humanitarian scenario, an ABM was used to simulated movement of rations to troops in an urban environment. Since the ABM used (MANA, developed by Lauren and Stephen, 2002) did not have a replenishment capability, friendly replenishment forces had to shoot their troops in order to feed them (Wolf 2003, Wolf et al. 2003). This out-of-the-box thinking was necessary in order to simulate this logistic function. In our seabasing logistics study, two other ABMs called Pythagoras (Northrop Grumman, 2003) and Socrates (L3 Communications, 2003) were initially explored to see if they could creatively simulate a replenishment capability. However, due to limitations in software development and the timing of this study, we decided to use a third ABM, SEAWAY.

Figure 5.   MV-22 Osprey (From Ref: Moore and Hanlon, 2003)

The validity and usefulness of ABMs remains an ongoing contention within the analysis community. The Marine Corps, through the prepotency of Project Albert (PA), is one of the leading agencies working to address this area of research. Specifically, the

Marine Corps is interested in exploring ways of sorting through the sample spaces generated by an agent-based approach to gain insight into real-life, operational problems. To date, the Marine Corps has ushered the development of several ABM environments (Horne and Johnson, 2002, 2003). These environments are useful in generating abstract models of real-world problems and exploring the human dimension of combat. The goal of the PA models is to gain insight, rather than specific numerical predictions. On the other hand, the SEAWAY model is an agent-based planning tool whose focus lies with the results and numbers at the end.

E.   SEAWAY AND THE SEABASE SCENARIO

The strength of an ABM in any military scenario is it allows the analyst to quickly model an abstraction of a problem, in this case, the logistic chain of the seabase. From the initial results of a number of runs of the program, one can look more closely at the parameters with the greatest influence. The general purpose of this thesis is to identify how and where ABMs will be used to support logistical decision-making in a seabase environment.

There are ABMs currently used by the Department of Defense that range from making limited attempts at replenishment actions to others whose main focus is representing logistics functions. Specifically, SEAWAY is a currently fielded Marine Corps program that plans, coordinates, and controls ship-to-objective delivery of supplies ashore. SEAWAY is a relatively new decision making tool expected to play an integral part in the naval and joint seabase logistic program. Additionally, Seaway is an agent-based system that assists seabase operations by providing total theater visibility of all ship borne asset items en route to onshore objectives. SEAWAY also monitors the execution of logistic plans and offers real-time decision solutions to complex problems. It can also be thought of as a software "tool kit" than can adapt itself to the user, to the maritime logistic support concept, and to the changing circumstances of a military contingency (CDM 2003).

The seabase scenario used in this study was developed and provided by the Seabasing Assessment done by representatives from OPNAV N7 and CDM

Technologies. Further details of the scenario will be provided in Chapter II, SEAWAY Model Description.

F. DATA FARMING

Data farming is an iterative technique that samples, and when necessary re-samples, areas of the data space that the analyst wants to research more closely. Although the ABM used in this analysis, the SEAWAY program, is a new ABM environment not yet familiar to most of the analysis community, data farming can still be used to explore the program's behavior.

In the more commonly used ABM environments, sampling and re-sampling normally occurs rapidly due to the use of supercomputers to execute thousands of model runs in a relatively short amount of time (MCWL 2004, Horne and Johnson 2002, 2003). By using a batch input process, the analyst can set the random number seed and input factor levels prior to execution. This contributes to the ability to execute hundreds of thousands of model runs in a timely manner. On the contrary, the SEAWAY program's inability to process batch inputs at the time of this research makes the manual input process time-consuming and prone to manual error input. As a result, data farming within the SEAWAY model is a great deal slower. The generation of a single run requires a minimum of two hours.

G. BENEFITS OF THE RESEARCH

There are a few areas where this thesis will be beneficial. First, because seabasing operations are going to be increasingly important over the next decade, the need to effectively model and analyze seabasing scenarios is critical to determine best practices for conducting seabasing operations. Second, by using a fielded program we were able to contribute to the developer's process improvement of the overall system. By becoming involved early in the fielding process, we are able to provide inputs on other ways to use the program in the field, i.e., expanding the input process to include batch processing and by introducing and developing a model in a pre-planning stage. Third, our analysis will provide insight into the factors contributing to the success or failure of the logistics chain of the seabase. Finally, we will show that structured sound analysis contributes to a successful "back of the envelope" approach. All of these benefits

ultimately contribute to this scenario being used as a template from which other seabase logistics scenarios can be analyzed.

H.   ORGANIZATION OF THE STUDY

In this thesis, we will evaluate a seabase scenario using the SEAWAY software "tool kit" and determine whether the specified parameters are capable of explaining variation in the stated measures of effectiveness. The specific approach we use is to select factors from a given scenario, apply a sampling technique to set factor combinations, and to use multiple regression models to fit the datasets in order to identify significant factor combinations. In Chapter II, we will describe the seabase scenario used within SEAWAY, along with more details of the SEAWAY program. In Chapter III, we will describe the data collection and analysis approach used to determine how several specific factors affect the measures of effectiveness. Finally, we will discuss the conclusions and our recommendations for future study in Chapter IV. ***This thesis illustrates how to apply data farming techniques to an agent-based software tool for planning the logistics operations of the seabase.***

II.   SEAWAY MODEL DESCRIPTION

A.   SEAWAY OVERVIEW

According to the developer,

> SEAWAY is a maritime logistic decision-support system that assists in executing seabase operations and in providing visibility on all cargo items in theater. Designed to operate in the Windows NT environment, SEAWAY employs a number of expert agents that collaborate with users to provide the information necessary for realistic and timely logistic support. In addition, the system offers a full range of warehousing and cargo churning functions aboard selected ships that comprise the seabase. SEAWAY tracks supply levels and files offloaded stocks for reorder.

(CDM, 2002).

SEAWAY provides end-to-end visibility for maritime logistic support during contingencies and supports OMFTS, STOM, and other joint force deep maneuver concepts. Among other capabilities, SEAWAY tracks supplies, projects availability, and coordinates and controls ship-to-shore and ship-to-objective delivery of supplies to the forces operating ashore. It also offers a range of functions vital to seabasing including the capability to locate and project timelines to access specific cargo items embarked aboard the seabase. (CDM, 2002)

1.   Agents

SEAWAY agents are able to automatically reason about current and simulated seabasing conditions. Specifically, in a planning mode the agents function as intelligent tools that are able to assess the logistics supportability of schemes of maneuver (SOMs) or courses of action (COAs) and develop delivery schedules within the constraints of limited transportation assets, environmental conditions, and the availability of supplies. In execution mode, the agents monitor current events and assist human operators in near real-time to adapt to the dynamically changing conditions of the execution environment (CDM Dec 2002). We now provide brief descriptions of the types of agents, and their activities.

11

Delivery agents monitor the statement of logistics requirements (SOLR). During mission planning, they generate a delivery plan on request. If this plan is unable to fulfill all the logistic requirements, they also generate alerts for both inventory and transport shortfalls. During a mission execution simulation, these agents monitor the delivery plan and corresponding SOLR, generate warnings for any deliveries outside of the designated delivery window, and generate alerts for any sorties that are canceled, aborted, or destroyed. During mission execution for actual seabase operations, the logistician can input changes in logistics requirements and/or information about canceled, aborted, or destroyed sorties in order to revise existing plans or delay some deliveries to a later time window.

The *Requirement agents* monitor the scheme of maneuvers (SOM), courses of action (COA) and any changes to the SOLR. During mission planning, they generate a SOLR on request. During mission execution simulation, these agents monitor the SOLR and generate recommendations if inventory levels at forward bases, seabase vessels and tactical bases fall below minimum quantity levels. These agents also generate warnings if the SOLR requests a high percentage of inventory available at all forward bases and/or if the SOLR requests more inventory than what is available at all forward bases. During mission execution for actual seabase operations, the logistician can input changes in logistics requirements in order to revise existing plans.

The *Inventory agents* monitor the SOLR and the delivery plan, noting the use of supplies on the critical item list (CIL). During a mission execution simulation, they continually monitor the available inventory and minimum quantity levels, monitor inbound vessels and aircraft, and generate warnings if inbound vessels or aircraft are delayed. These agents also generate warnings if inventory levels at the forward bases, seabase vessels and tactical bases fall below their minimum quantity levels.

For this research, the following agents were disabled in order to create a static environment. The *Movement agents* monitor all tactical control measures (TCM), generate recommendations, warnings, and alerts for TCM obstructions, and generate warnings when TCM distance is greater than the unit's lowest vehicle range. The *Route agents* monitor all routes and enemy unit locations relative to same routes. During

12

mission execution simulation, these agents generate recommendations when enemy unit's weapon effective range is greater than its proximity to an unused route, warnings when effective range is greater than its proximity to an unapproved sortie, and alerts when effective range is greater than its proximity to a route used by an approved sortie. The *Siting agents* monitor all landing zones, all TCMs, and all Forward Arming and Refueling Points (FARPs). During the mission execution simulation, these agents generate: recommendations, warnings, or alerts for inappropriate landing zone sites; generate recommendations if a TCM does not have a landing zone within a reasonable distance; or generate warnings if the area of operations does not include an adequate number of FARPs. The *Tactical agents* monitor enemy unit locations relative to friendly units, and all calls for fire (CFF). During the mission execution simulation, these agents generate a basic fires plan in support of re-provisioning and delivering supplies and equipment, and generate CFF alerts for targeting friendly unit and unanticipated friendly units. The *Weather agents* monitor weather reports and conditions. During the mission execution simulation, these agents generate recommendations, warnings or alerts when weather conditions will affect inventory or transport operations. The *Distribution agents* monitor all SOLRs, all delivery plans, and all combat service support (CSS) units. During the mission execution simulation, these agents generate tactical re-provisioning distribution plans and alerts related to existing conditions preventing proper distribution of supplies.

B. SEABASE SCENARIO IN SEAWAY

1. SEAWAY Process

For this thesis, we focus on the portion of the SEAWAY process that begins with the generation of the Statement of Logistics Requirements (SOLR). The SOLR report recommends the material needed to be delivered ashore, the requested quantities, the targeted landing zone, and the delivery time window. The SEAWAY Notion to Decision process is displayed in Figure 6.

Once the SOLR is generated, the first major decision point has been reached. At this time, the staff logistician would assess the plan's acceptability and either (i) execute the resulting acceptable plan; (ii) if the initial plan is unacceptable, then modify and

13

regenerate a new plan; or (iii) if no acceptable plans are found even after regenerating one or more new plans, develop new COAs and begin the process over (CDM, 2003).

Using SEAWAY and LOGGY Tools:
From Notion to Decision
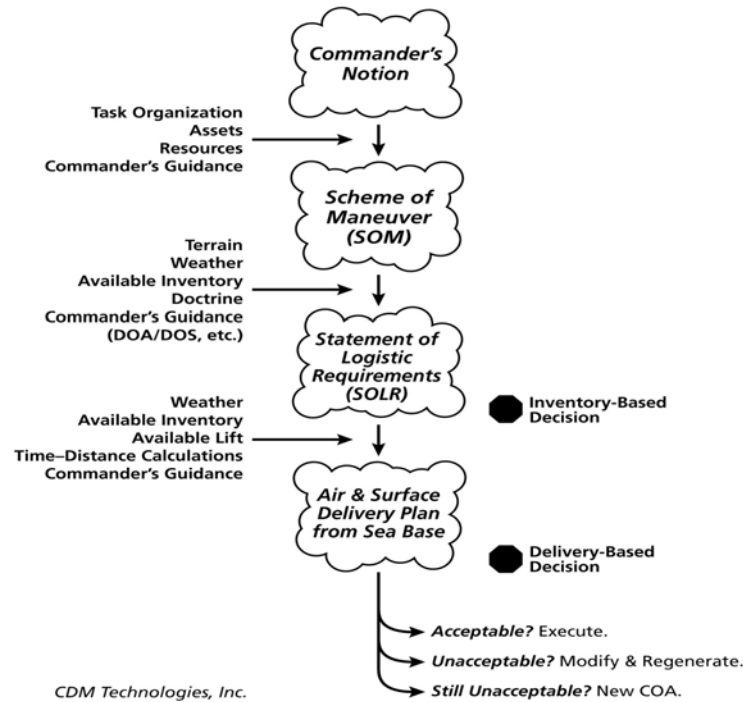
Figure 6.   SEAWAY – Notion to Decision (From Ref: CDM, 2003)

Once the plan's acceptability has been determined, the next step in SEAWAY is to convert the SOLR into an Air and Surface Delivery Plan. The data required to complete the process were acquired and re-used from a seabasing assessment done by representatives from OPNAV N7 and CDM Technologies on July 28, 2003.

The seabase scenario focused on utilizing the same one phase scheme of maneuver (SOM) with different delivery vertical asset mixes covering a varying seabase to objective landing zone distance. "In order to facilitate future asset requirements, the scenario specified and developed new item types (e.g. MV-22, AAAV, etc.), new consumables (e.g. 30mm and High Mobility Artillery Rocket System (HIMARS) ammunition), new consumption rates, and detailed tables of equipment for all units in the

MEB. The type of items were of Class I – Water, Class III – Fuel, and Class V – Ammunition" (OPNAV and CDM, 2003).

This scenario conducted was an amphibious operation on the Korean peninsula using the 2015 MEB. All units were employed, including units keeping the landing zone (LZ) open at the objectives. The SOM included a single sea echelon area where the approach and retirement lanes remained constant for each run of the program. Figure 7 depicts the area of operations and the Seabase echelon.
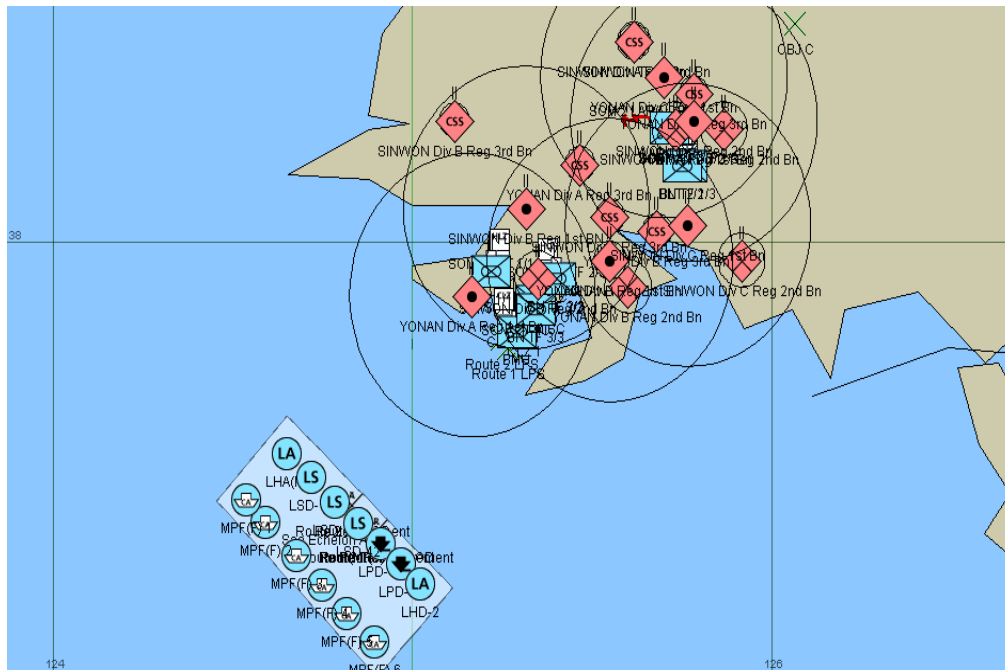
Figure 7.   SEAWAY Seabase Area of Operations

2.   Scenario 2015 Assets

For the given scenario, the 2015 MEB is embarked on seven amphibious ships split across two Expeditionary Strike Groups (ESGs). Each ESG is composed of a large deck amphibious assault ship (LHD or LHA(R)) and supporting transport dock ships (LPD) and landing dock ships with cargo variants (LSD). Additionally, six Maritime Prepositioning Force (MPF) ships are co-located with the amphibious ships to download equipment and vehicles in the tactical area of operations. Table 1 outlines the ships assigned to each ESG and the number of helicopter spots available per ship type.

Table 1.   Naval Support Ships 2015

GROUPS	SHIP	MAX HELO SPOTS
ESG 1	LHD-2	5
	LPD-17	4
	LSD-42	1
	LSD-49	1
ESG 2	LPD-18	4
	LSD-43	1
	LHA(R)	2
MPF(F)	MPF(F)-1	6
	MPF(F)-2	6
	MPF(F)-3	6
	MPF(F)-4	6
	MPF(F)-5	6
	MPF(F)-6	6

In addition to the surface assets listed above, the 2015 MEB utilized two vertical lift platforms embarked across both ESGs and MPF(F)s. There were a total of 51 MV-22's (future assets) and 18 CH-53's (current assets, Figure 8). Of those totals, the MV-22's were further split with nine aircraft on the LHD and 42 aircraft embarked on the MPF(F). For the CH-53's, five aircraft were on the LHD and 13 aircraft were embarked on the MPF(F).

3.   **Scenario Assumptions**

In order to simplify various factors in the scenario, we chose to make assumptions regarding the surface crafts, agents, the availability of assets and other miscellaneous rates.

Figure 8.   CH-53 landing on Deck (From Ref: Global Security, 2004)

The following surface crafts were incorporated into the scenario by the seabasing assessment.   There was one Landing Craft Air Cushion (LCAC) embarked on the LHA(R) (Figure 9), one Littoral Craft Unit (LCU) assigned to work with the LPD-17, and one heavy lift LCAC (HL-LCAC) embarked on one of the six MPF(F)s. Due to limiting the focus of this research to vertical lift assets, surface craft factors remained the same for each program run.

In order to focus on the logistic aspect of the scenario, the Route, Siting, Tactical, Weather and Distribution agents were turned off in order to create a static environment. If they had been turned on, the program might not run because these agents might not allow the logistic leg of the delivery plan to commence. For example, under adverse weather conditions all vertical lift operations might be cancelled, or under combat conditions the debarkation points and/or flight deck crews might be appropriated for combat operations, rather than logistics re-supply efforts. Additionally, the Inventory agent was disabled due to an assumption that material aboard the seabase echelon was being re-supplied by the Combat Logistics Force (CLF) ships, therefore it was not expected to run out of stock on any items. This left the Requirements and Delivery agents as the only active agents.

Figure 9.   LHA(R) Future Design (From Ref: CNO N75, 2004)

Under normal amphibious operations, aircraft are unavailable for operational missions, repair, maintenance or reserved for other missions such as logistics. This scenario assumed there were zero aircraft down for maintenance or reserved for other missions, this allowed all 51 MV-22ss and 18 CH-53s to be available for logistics operations.

The following miscellaneous parameters were kept constant for every program run: the ordnance consumption was at the assault rate; the cycling rate of vertical assets was four sorties/transport/day; a SOLR represented one days worth of supply; the delivery plan represented one day's worth of delivery.

Once the details of the baseline scenario were documented and the focus of study was defined, it was time to run the SEAWAY program. This step proved to be the most time-consuming and was the area of focus for this research. The details regarding how we varied factors to investigate the chosen MOEs, and the amount of time required, are discussed in Chapter III, Design of Experiments.

III. DESIGN OF EXPERIMENTS

A. DATA COLLECTION AND SOURCES

In order to minimize the scope within the SEAWAY seabase scenario, this research focused on analyzing the vertical lift assets, namely 51 MV-22s and 18 CH-53s. These assets were split across the LHD naval platform and the MPF(F)s. In order to gain a better understanding of the contributions between a current vertical lift asset (CH-53) and a future vertical lift asset (MV-22), three measures of effectiveness (MOE) were chosen.

The Total Number of Aircraft Sorties was the summation of sorties for both MV-22's and CH-53's. The individual data for total sorties of MV-22's and CH-53's were also available. Due to its longer range capabilities, we would expect to see the MV-22 complete more sorties at longer distances versus the CH-53 completing more sorties at the shorter distances.

The Total Aircraft Sortie Time of Aircraft Sorties was the summation of time for both MV-22's and CH-53's. The individual data for total time of MV-22's and CH-53's were also available. Due to its longer range and higher external speed, we would expect to see the MV-22 complete sorties in a quicker turn around time than the CH-53.

The Total Tons Delivered was the summation of total tons delivered for both MV-22's and CH-53's. The individual data for total tons delivered by MV-22's and CH-53's were also available. Due to its greater lift capacity, we would expect to see the CH-53 delivering the bulk of the material versus the MV-22 across all distances within its range.

Due to the deterministic nature of the SEAWAY program, only one run was needed for each combination of factor values. We used a sampling technique in order to introduce variations from the baseline capabilities into the given scenario. By using this technique, the chosen eleven factors could be observed to determine if their values could explain any variation in the explored resulting measures of effectiveness.

The general methodology we used to collect and analyze the data was to select the factors for the experiment, apply the technique of a Latin Hypercube (LHC) design to set

the factor combinations, and to use multiple regression models to fit the datasets in order to identify significant factor combinations.

1.   Factor Selection

The selection of the eleven factors (Table 2) was extracted from the baseline scenario provided by the Seabasing Assessment done by representatives from OPNAV N7 and CDM Technologies. In order to establish a baseline scenario, factor values were chosen to maximize the overall delivery capabilities. Specifically, nine of the eleven factor's starting values were set to maximum values and two were set to minimum values. As a follow on, a fine-tuning of selection factors was based on the following question:

- "As the distance between the seabase and the landing zone increases (either because the maneuver ventures deeper inland or because the seabase is farther from shore) what is the appropriate ratio between lift capacity and speed of a vertical platform in order to maintain required delivery timelines?" (Becker, 2003)

Table 2.   Summary Information for Experimental Factors

FACTOR	UNIT	MAX	MIN	INCREMENT	NUM LEVELS
Distance to Seabase	Nm	216	24	6	33
External Speed of MV-22	Knots	148	84	2	33
External Speed of Ch-53	Knots	108	44	2	33
Lift Capacity of MV-22	Lbs	9,856	4,928	150	33
Lift Capacity of CH-53	Lbs	29,973	20,085	300	33
Delivery Window	Min	615	120	15	33
Spot re-use, after take-off	Min	84	20	2	33
Range of MV-22	Nm	495	335	5	33
Range of CH-53	Nm	395	235	5	33
MPF(F) Logistics	Ea	6	1	1	6
L-Class Logistics	Ea	5	1	1	5

2.   Design of Experiments

Based on the initial selection of eleven factors, a sampling technique was used that would allow a full range of analyzing the combinations. This method was an ordinary Latin Hypercube (LHC) sampling technique, where all portions of the distribution of the range of a factor are divided into equal increments. The LHC then samples once, at random from within each of the factor distributions. The values drawn are assigned as the factor settings for the first run of the simulation. This technique is then repeated without replacement for the second, third, and all subsequent runs. By the end of the LHC process, the distribution of possible values for the factor have been uniformly sampled resulting in a column filled with randomly sampled and randomly assigned factor settings that cover the number of simulation runs.

LHC designs are very useful when there are many factors of interest and the analyst does not wish to make strong assumptions about the nature of their relationship to the MOEs (see, e.g., Sanchez and Lucas 2002, Kleijnen et al., 2004, Cioppa 2003). The analysis is more straightforward if there is little or no correlation between the columns while still maintaining good space filling qualities. "A design matrix will be classified as nearly orthogonal if it has a maximum pairwise correlation no greater than 0.03 and a condition number no greater than 1.13" (Cioppa, 2003). For the eleven-factor design in the Appendix, two of the factors could take on only a handful of levels, so we were unable to use the orthogonal design suggested by Cioppa (2002, 2003) without rounding some factor settings. Despite this rounding, the maximum correlation between factors (columns) was only 0.059 with a condition number of only 1.3. This indicated our design still had reasonably good space-filling and orthogonality qualities. See Appendix for the complete description (including factor settings) for the 11 factor, 33 run LHC matrix used for our analysis.

a.   Simulation Runs

Once we determined the LHC design, it was time to run the SEAWAY program. In addition to the 33 runs dictated by the LHC, an additional run was

conducted using the factors' baseline values. This run established a base case for the scenario and resulted in a total of 34 runs.

The SEAWAY program runs were done at CDM technologies in San Luis Obispo, CA. By visiting CDM, we were able to use their six laptop SEAWAY computers. The time to set up and run the 34 program excursions spanned a two-day period over 22 hours. Each simulation run averaged a forty-five minute set-up time, plus an average of two to fours hours to complete the simulation run, followed by forty-five minutes to capture data. Each of the laptop computers were identical to those Marine Corps personnel would use in the field. Computing capabilities required each laptop to meet a minimum of 1 GHZ processing speed and 1 GB RAM. A local version of the SEAWAY program was installed on a Project Albert laptop with 2.5 GHZ processing speed and 768 MB RAM. The laptop, despite not meeting minimal requirements for RAM, was useful in re-running simulation runs locally. The local laptop ran noticeably slower than laptops at CDM Technologies.

There were some inconveniences associated with running the SEAWAY program 34 times. First, since the SEAWAY program uses a GUI interface for user inputs, this proved to be a hindrance when running the program multiple times. A possible solution would be to have SEAWAY configured to process batch inputs. Since SEAWAY was not capable of batch processing at the time of this research, the author was resigned to input and vary each run's factors manually. CDM representatives were very helpful in assisting with this process. The manual input of varying factors did cause some 'fat finger' errors. Specifically, input errors identified during the data capture phase meant that five program runs were required to be re-run on the local laptop.

3.   Statistical Software Package

Before analysis began, we consolidated the data using two statistical software packages. Since Microsoft ® Excel was a familiar program, SEAWAY post reports were saved as text files and imported into Microsoft ® Excel. In Excel, we manipulated the text files into useable worksheets to support the chosen measure of effectiveness. We then imported the data files into JMP a Statistical Discovery Software ™ package.

JMP is a product of the SAS Institute ® and is advertised as a software package for interactive statistical graphics (JMP, 2002). This software is designed to be a point–and-click product made for the field analyst. JMP includes:

- A spreadsheet for viewing, editing, entering, and manipulating of data.

- A broad range of graphical and statistical methods for data analysis.

- Options to select and display subsets of the data.

- Facility for grouping data and computing summary statistics

We found JMP to be a user-friendly data analysis package with well-developed graphics capabilities.

B.   MULTIPLE REGRESSION ANALYSIS

While there are many analysis techniques that could have been applied to the dataset, we decided to use multiple regression analysis. The purpose of multiple regression is to learn more about the relationship between several independent or predictor variables and a dependent variable. It can establish that a set of independent variables explains a proportion of the variance in a dependent variable at a significant level (significance test of R^2). Power terms (e.g., quadratic or cubic terms) can be added as independent variables to explore curvilinear effects. Cross-product terms (two-way interactions) can be added as independent variables to explore interaction effects (Devore, 2000).

1.   Regression Equation

The general computational problem that needs to be solved in multiple regression analysis is to fit a straight line to a number of points. In the simplest case, you would have one dependent and one independent variable. However, in the multivariate case, the objective is to find a model that relates the dependent variable Y to more than one independent or predictor variable (Devore, 2000). In general, the regression model equation can be expressed as the following:

$$Y = c + \sum_{i=1}^{n} \beta_i x_i + \varepsilon$$

where:
   Y   dependent variable
   x_i independent variable
   β true, unknown, regression coefficients
   c the constant, y-intercept
   ε random error term
   n number of independent variables

Since the equation above has no interaction effects, this will be the equation for the main effects.

2.   Quadratic Effects

Next, we added quadratic terms to the model to incorporate the curvilinear effects of an independent variable on a dependent variable. However, when attempting to fit polynomials of an independent variable whose mean does not equal zero, difficulties can result due to multicollinearity.

$$Y = c + \sum_{i=1}^{n} (\beta_i x_i + \beta_{n+i} x_i^2) + \varepsilon$$

where:
   Y   dependent variable
   x_i independent variable
   β true, unknown, regression coefficients
   c the constant, y-intercept
   ε random error term
   n number of independent variables
   $2n$ number of terms

3.   Two-way Interactions

We next explored how incorporating the joint effect of two variables on a dependent variable, in addition to their separate main effects, could improve the original model. One adds interaction terms to the model as cross-products of the standardized independents, typically placing them after the main effects independent variables. Since cross-product terms may be highly correlated with the corresponding independent

variables in the regression equation, it is suggested the cross-product independent variables also be "centered". The JMP Statistical software package automatically "centered" the independent variables in each of the models.

$$Y = c + \sum_{i=1}^{n} \beta_i x_i + \left[\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{i,j} x_i x_j \right] + \varepsilon$$

where: Y   dependent variable

x_i independent variable

β_i true, unknown, regression coefficients

c   the constant, y-intercept

ε random error term

n   number of independent variables

$n + n(n-1)/2$ total number of terms

Note that in practice we could skip step 3 and proceed directly to step 4. We include the two-way interaction model without quadratic effects in our discussion for completeness.

4.   Quadratic Effects & Two-way Interactions

Adding both quadratic and interaction terms to the model allowed for both effects to be incorporated as independent variables on a dependent variable in addition to their separate main effects.

$$Y = c + \sum_{i=1}^{n} (\beta_i x_i + \beta_{n+i} x_i^2) + \left[\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{i,j} x_i x_j \right] + \varepsilon$$

where: Y   dependent variable

x_i independent variable

β_i true, unknown, regression coefficients

c   the constant, y-intercept

ε random error term

n   number of independent variables

$2n + n(n-1)/2$ total number of terms

5.   Assumptions

The following assumptions regarding ε apply for the regression fitting technique and the statistical testing procedures (Devore, 2000 and Hamilton, 1992).

- Errors must follow a normal (Gaussian) distribution.

$$\varepsilon_i = N(0, \sigma^2) \qquad \forall \, i$$

- Errors must be identically distributed with zero mean and constant variance.

$$E[\varepsilon_i] = 0 \quad \forall \, i$$
$$Var[\varepsilon_i] = \sigma^2 \quad \forall \, i$$

- Errors are uncorrelated with each other.

$$Cov[\varepsilon_i, \varepsilon_j] = 0 \quad \forall \, i \neq j$$

6.   Comparing Regression Models

When conducting regression analysis, a good starting point is to look at the F-test. The F-test is used to test the overall significance of the regression model as a whole. If Prob (F)<0.05, then the model is considered to be significantly better (at level $\alpha = .05$) than would be expected by chance. We then reject our null hypothesis of no linear relationship between Y and the independent variables (X) (Devore, 2000).

H_0 :   There is no linear relationship between Y and any of the independent variables (X)

H_a :   There is a relationship between Y and at least one of the independent variables (X)

The second step in the regression analysis is to look at the R^2 values. R^2 is the proportion of variance in the dependent variable (Y) explained jointly by the independent variables (X), and can assume values between 0.0 and 1.0. For example, if $R^2 = 1.0$ this indicates the model is successful in explaining all of the Y variation, and if $R^2 = 0.0$ then the regression error is as large as it would be if you simply guessed the mean for all cases of Y (Devore, 2000 and Hamilton, 1992). Since R^2 never decreases when additional

terms are added to a model, our goal was not to identify models that maximized R^2. For each MOE, we want to find a simple regression model, i.e., one with the fewest number of terms, for which R^2 is close to 1.0.

7.   Determining the Significance of Terms in the Regression Model

During the exploration of the four models, we determined the significant terms within each model prior to moving forward to the next model. The idea was to verify the factor combinations themselves both qualitatively and quantitatively. The author's judgment was used to qualitatively determine whether including or excluding specific terms made sense. Quantitatively, the student t-test was used to determine the significance of a particular term by assessing the significance of individual β coefficients. A common rule of thumb is to drop from the equation all variables not significant at the 0.05 level or better.

In JMP, these procedures were automated. Therefore, it was very easy to test over the range of factor combinations.

8.   Plotting Regression Models

Once we choose the "simplest" regression model, two specific plots were used as a quick validation of the goodness of fit. The first plot, "actual vs. predicted", is a quick visual display useful for verifying the general pattern of the actual dependent variable (Y). Ideally, one would want all points to fall along a diagonal line, which would imply that the independent variable (X) is effective in predicting the dependent variable (Y). The value of R^2 should validate these observations. If R^2 is close to 1.0, then the plot will reflect a diagonal line, if R^2 is closer to 0.0, there can still be a linear relationship but the points will be more scattered around the line. A useful option for these plots are the confidence curves. In this thesis, they are visible by the "3 red-bands" or "3 dotted diagonal curves/lines". The confidence curves indicate whether the test is significant at the 5% level by showing a confidence region for the line of fit. If the region between the curves crosses the horizontal line, then the model is significant. If the region contains the horizontal line, then the model is not significant. The horizontal line is the sample mean of the response (JMP, 2002).

The second plot, the "standardized residuals vs. predicted", is also a quick visual in verifying the spread or the evenly spaced distribution of all points. If the model is correct, the plot should show a random scatter, with no linearity or other types of patterns. The detection of any type of pattern would violate our assumptions of the errors being independently distributed with mean equal to zero and constant variance (Devore, 2000).

Other useful optional plots were also used to interpret and analyze the final model through graphical methods. These plots will be discussed in detail in the next section. In summary, verifying the numerical results of the final model's equations will be confirmed graphically by looking at the Interaction Plots, the Prediction Profiler, the Actual vs. Predicted plots, and the Standardized Residuals vs. Predicted plots.

C. MODEL COMPARISONS

1. Fitting the Main Effects Only Models

Initial analysis began by looking at the eleven factors in the Main-Effects Model for each of the measures of effectiveness. The results are listed in Table 3.

Table 3. Main-Effects Model Summary of Results

Regression Results	Total Aircraft Tons	Total Aircraft Sorties	Total Aircraft Time
R^2	.7873	.3841	.1713
F test p-value	<.0001	.3158	.9344
# Factors	11	11	11

Based on the lack of significance, as indicated by the F-test p-values > 0.05 for two of the three MOEs, and the relatively low R^2 values for each of the measures of effectiveness, the next step in the analysis was to introduce the quadratic effects to the Main Effects Only Model.

2. Fitting the Quadratic Model

Due to the lack of significance and corresponding low values of the R^2, we decided to introduce the squared terms. The number of the available terms, now doubled to 22 terms, poses a sizeable second-order model. In order to come up with a simpler quadratic model, we used the stepwise regression procedure in JMP to add in terms having the most influence on R^2 provided the chosen significance level is met. The significance level criteria for each independent variable added to the model was its p-value <0.05. As a recurring action, as the stepwise regression process adds terms to the model, it also goes back to verify previously added terms and re-validates their significance level. The end result is a model containing only significant terms that improve the value of R^2 the most. As a rule, if the resulting model's independent variables included the squared term, the main effect variable was also included. Since multicollinearity expresses a linear relationship between two or more of the independent variables, it can prevent the estimation of the individual coefficients of our independent variables (Hamilton, 1992). In order to solve the multicollinearity problem, prior to adding the quadratic term in the model, the independent variable should be "centered" (by subtracting the mean) prior to applying the quadratic transformation. The JMP Statistical software package automatically "centers" the independent variable by subtracting off its sample mean when including quadratic terms in each of the models. Table 4 is a summary of the results for each of the measures of effectiveness.

3. Fitting the Two way Interactions Model

Since the significance and R^2 values of all three models improved, but there still seemed to be room for improvement, we decided to introduce the interactions of the main terms. This Two-Way Interaction Effects model included the eleven factors from the Main Effects Model plus the introduction of the paired terms across the eleven factors. Due to the impossibility of simultaneously introducing 55 potential interactions into a model constructed from only 34 data points, a full second-order model cannot be fit. As with the Quadratic Effects model, the stepwise regression procedure in JMP was used to add in factors having the most influence. Each independent variable with a p-value <0.05 was individually added. As a rule, if a variable was included as an interaction term, the main effect variable was also included. As with the previous interactions, the "centering"

of the independent variable was required in order to minimize multicollinearity. The JMP Statistical software package automatically "centers" the independent variable by subtracting off its sample mean when including two-way terms in each of the models. Table 5 is a summary of the results for each of the measure of effectiveness.

Regression Results	Total Aircraft Tons	Total Aircraft Sorties	Total Aircraft Sorties Time
R^2	.9347	.6433	.8132
F test p-value	<.0001	<.0001	<.0001
# Factors	7	3	7
Range of MV-22	X	X	X
D to Seabase	X	X	X
(D to Seabase)^2	X	X	X
Spot Re-use Time	X		X
(Spot Re-Use Time)^2	X		X
Lift of MV-22	X		X
(Lift of MV-22)^2	X		X

Table 4.   Quadratic Effects Model Summary of Results

4.   Fitting the Final Model

Despite the apparent "success" of the Two-way Interactions and Quadratic Models, we decided to go further in our analysis in order to see if by allowing both types of effects, we could reduce the number of terms while still keeping the percentage of explained variability high. The final objective was to find the best equation that could include two-way interactions, 2nd degree polynomial quadratic effects, and main effects. As with the previous models, the stepwise regression procedure in JMP was used to add in factors having the most significance. Ultimately, each independent variable with a p-

value <0.05 was individually added to the model. As a rule, if the resulting model's independent variables included the squared or interaction term, the main-effect term was also included. In order to solve the multicollinearity problem, prior to adding the quadratic and two-way terms in the model, the independent variable should be "centered" (by subtracting the mean) prior to applying the quadratic transformation. The JMP Statistical software package automatically "centers" the independent variable by subtracting off its sample mean when including quadratic and two-way terms in each of the models.

Reviewing the results in Table 6, the three models were able to explain 89-94% of the scenario's variability with only 5-12 terms, versus the 14-17 terms identified in the Two-way Interaction model and the 77 potential terms at the onset of the analysis.

When the SEAWAY process results in an unacceptable Air and Surface Delivery Plan from the seabase, this parsimonious final model will provide the time-crunched logistician a "fast and furious" method for identifying significant factors to modify that will be more likely to provide an acceptable delivery plan. A spreadsheet program like Microsoft Excel ® can be used to employ the resulting equations easily. This spreadsheet tool is a great complement to the SEAWAY program, especially when time constraints do not allow for running the SEAWAY program multiple times.

5.   **Interpreting the Terms in Final Model**

Verifying and interpreting the terms that resulted in the final model was an ongoing process throughout the analysis. During the evaluation of the final model, we qualitatively verified the acceptance of the factor combinations themselves by including or excluding specific factor combinations. Quantitatively, we used the student t-test to determine the impact of specific terms by assessing the significance of the corresponding beta coefficients. The rule of thumb used during this analysis was to drop from the equation all variables not significant at the 0.05 level or better. The exception to this was when the main effect independent variables were added back in when either the squared term or its two-way interaction term was chosen during the stepwise regression process. These terms exceed the 0.05 threshold when viewing the factors in Tables 7-9.

Table 5.   Two-way Interactions Model Summary of Results

Regression Results	Total Aircraft Tons	Total Aircraft Sorties	Total Aircraft Sortie Time
R^2	.9769	.9476	.9289
F test p-value	<.0001	<0.001	<.0001
# Factors	15	17	14
Spot Re-use Time		X	
Range of MV-22	X	X	X
Range of CH-53	X	X	X
D to Seabase	X	X	X
Ext Speed CH-53	X	X	X
Ext Speed MV-22		X	X
Lift of MV-22	X	X	
Lift of CH-53	X		
Delivery Window	X	X	X
MPF(F) Log Dbk Pts	X	X	X
L Log Dbk Pts	X	X	X
(Range of MV-22)*(D to Seabase)	X	X	X
(Range of MV-22)*(Ext Speed MV-	X	X	
(D to Seabase)*(Ext Speed MV-22)^2	X	X	X
(Range CH-53)*(Ext Speed CH-53)	X	X	X
(Delivery Window)*(MPF(F) Log	X	X	X
(Range CH-53)*(L Log Dbk Pts)	X	X	X
(Delivery Window)*(L Log Dbk Pts)		X	X

Table 6.　　　Final Model Summary Results

Regression Results	Total Aircraft Tons	Total Aircraft Sorties	Total Aircraft Sorties Time
R^2	.9363	.9241	.8895
F test p-value	<.0001	<.0001	<.0001
# Factors	5	12	10
Spot Re-use Time		X	
Range of MV-22	X	X	X
Range of CH-53			
D to Seabase	X	X	X
Ext Speed CH-53			
Ext Speed MV-22			X
Lift of MV-22	X	X	X
Lift of CH-53		X	X
Delivery Window			X
MPF(F) Log Dbk Pts			
L Log Dbk Pts		X	
(D to Seabase)^2	X	X	X
(L Log Dbk Pts)^2		X	
(D to Seabase)*(Lift MV-22)			X
(Ext Speed MV-22)*(Lift CH-53)			X
(Lift of CH-53)*(Del Window)			X
(Range MV-22)*(D to Seabase)	X	X	
(Spot Re-use)*(Lift MV-22)		X	
(Range MV-22)*(Lift CH-53)		X	
(Range MV-22)*(L Log Dbk Pts)		X	

Table 7.   Parameter Estimates – Total Aircraft Sorties

Term	Prob>|t|
Intercept	<.0001
Spot Re-use Time	0.0259
Range MV-22	<.0001
D to Seabase	<.0001
D to Seabase*D to Seabase	<.0001
Lift MV-22	0.3464
Lift CH-53	0.7674
L Log Dbk Pts	0.7767
L Log Dbk Pts* L Log Dbk Pts	0.0028
Range MV-22*D to Seabase	<.0001
Spot Re-use Time*Lift MV-22	0.0200
Range MV-22*Lift CH-53	0.0001
Range MV-22* L Log Dbk Pts	0.0500

Table 8.   Parameter Estimates – Total Aircraft Sortie Time

Term	Prob>|t|
Intercept	0.6748
Range MV-22	<.0001
D to Seabase	0.3089
(D to Seabase-117.206)*(D to Seabase-117.206)	<.0001
Ext Speed MV-22	0.5242
Lift MV-22	0.0765
Lift CH-53	0.8004
Dlvr Window	0.3755
(D to Seabase-117.206)*(Lift MV-22 -7468.71)	0.0026
(Ext Speed MV-22-117)*(Lift CH-53-25175.2)	<.0001
(Lift CH-53-25175.2)*(Dlvr Window-368.824)	0.0100

Table 9.   Parameter Estimates – Total Aircraft Tons

Term	Prob>|t|
Intercept	0.0002
Range MV-22	0.0013
D to Seabase	<.0001
(D to Seabase-117.206)*(D to Seabase-117.206)	<.0001
Lift MV-22	0.0069
(Range MV-22-417.5)*(D to Seabase-117.206)	0.0015

6. Evaluating Final Model Results

The results of the model were interpreted and analyzed through numerical and graphical methods. The resulting equations when used with a spreadsheet can provide a "back of the envelope" solution for each of the three MOEs immediately. The signs of the beta coefficients in conjunction with the equations can be used to show the effect (positive or negative) each resulting term will have on the MOE. Verifying the numerical results of the equations can be confirmed graphically by looking at the Interaction Plots, the Prediction Profiler, the Actual vs. Predicted plots, and the Standardized Residuals vs. Predicted plots.

The resulting equations from the Final Models for the three MOEs are shown in equations (3.1), (3.2), and (3.3):

3.1. Total Aircraft Tons Model Equation

$$\begin{aligned}
\text{Total Aircraft Tons} = {} & 336.62 + 0.58*(RangeMV22\text{-}417.50) - 2.36*(DtoSeabase\text{-}117.21) - \\
& 0.0204*(DtoSeabase\text{-}117.21)^2 + 0.016*(LiftMV22\text{-}7468.71) + \\
& 0.011*(RangeMV22\text{-}417.50)*(DtoSeabase\text{-}117.21)
\end{aligned}$$

3.2. Total Aircraft Sorties Model Equation

$$\begin{aligned}
\text{Total Aircraft Sorties} = {} & 61.97 - 0.19*(SpotReuse\text{-}51.35) + 0.17*(RangeMV22\text{-}417.50) - \\
& 0.19*(DtoSeabase\text{-}117.21) - 0.0045*(DtoSeabase\text{-}117.21)^2 - 0.0009*(LiftMV22\text{-}7468.71) - \\
& 0.00015*(LiftCH53\text{-}25175.21) + 0.30*(LLogDbkPts\text{-}3.15) + \\
& 3.84*(LLogDbkPts\text{-}3.15)^2 + 0.0036*(RangeMV22\text{-}417.50)*(DtoSeabase\text{-}117.21) - \\
& 0.00012*(SpotReuse\text{-}51.35)*(LiftMV22\text{-}7468.71) + \\
& 0.000044*(RangeMV22\text{-}417.50)*(LiftCH53\text{-}25175.21) - \\
& 0.0512*(RangeMV22\text{-}417.50)*(LLogDbkPts\text{-}3.15)
\end{aligned}$$

3.3. Total Aircraft Sortie Time Model Equation

$$\begin{aligned}
\text{Total Aircraft Sortie Time} = {} & 26.54 + 0.45*(RangeMV22\text{-}417.50) - 0.09*(DtoSeabase\text{-}117.21) - \\
& 0.02*(DtoSeabase\text{-}117.21)^2 + 0.15*(ExtSpeedMV22\text{-}117.00) - \\
& 0.0056*(LiftMV22\text{-}7468.71) + 0.0004*(LiftCH53\text{-}25175.21) + \\
& 0.03*(DlvrWindow\text{-}368.82) + 0.0002*(DtoSeabase\text{-}117.21)*(LiftMV22\text{-}7468.71) + \\
& 0.0005*(ExtSpeedMV22\text{-}117.00)*(LiftCH53\text{-}25175.21) + \\
& 0.00003*(LiftCH53\text{-}25178.21)*(DlvrWindow\text{-}368.82)
\end{aligned}$$

Once the final model has been determined, other useful analysis includes looking at the signs of the resulting estimated beta coefficients. The estimated beta coefficients are the average amount the dependent variable (Y) increases (+) or decreases(-) when the independent variable (X) increases one unit while the other independent variables are held constant (Devore 2000). Looking at Total Aircraft Tons, as the Distance to the Seabase increases by one unit, Total Aircraft Tons decreases (-). Conversely, as the Range and Lift of the MV-22 increases by one unit respectively, Total Aircraft Tons increases. Table 10 summarizes the signs for each of the estimated betas across the three MOEs:

Table 10.   Final Model Beta Coefficients

Term	Total Aircraft Tons	Total Aircraft Sorties	Total Aircraft Sortie Time
Spot Re-use Time		-	
Range of MV-22	+	+	+
Range of CH-53			
D to Seabase	-	-	-
Ext Speed CH-53			
Ext Speed MV-22			+
Lift of MV-22	+	-	-
Lift of CH-53		-	+
Delivery Window			+
MPF(F) Log Dbk Pts			
L Log Dbk Pts		+	
(D to Seabase)^2	-	-	-
(L Log Dbk Pts)^2		+	
(D to Seabase)*(Lift MV-22)			+
(Ext Speed MV-22)*(Lift CH-53)			+
(Lift of CH-53)*(Del Window)			+
(Range MV-22)*(D to Seabase)	+	+	
(Spot Re-use)*(Lift MV-22)		-	
(Range MV-22)*(Lift CH-53)		+	
(Range MV-22)*(L Log Dbk Pts)		-	

Other useful plots when analyzing the results of the Final Model are the Interaction Plots and the Prediction Profiler Plots. The Interaction Plots will show evidence of interactions between the terms as nonparallel lines. When the lines appear dotted rather than solid, there is no corresponding interaction term in the model.

For the first MOE, the Interaction Plot in Figure 10 shows there are interactions between the Range of the MV-22 and the Distance to the Seabase main effects. For example, looking at the lower left cell the effect of Distance to the Seabase is smaller at the longer ranges of the MV-22, but it diverges for the shorter ranges of the MV-22.
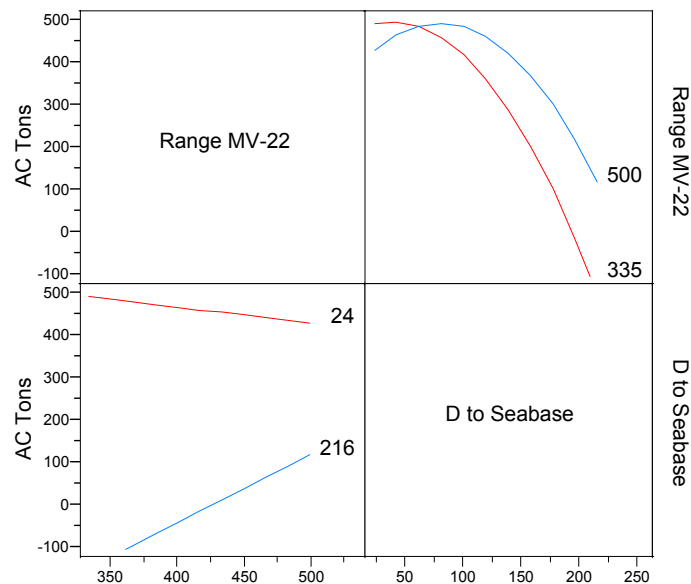
Figure 10.   Aircraft Tons Interaction Plot

When looking at the Prediction Profiler Plots, a prediction trace for each independent variable (X) is the predicted response as one variable is changed while the others are held constant at the current values. The Prediction Profiler re-computes the traces as you vary the value of an independent variable (X).

Since the Distance to the Seabase was a common factor across all three MOEs, Figure 11 displays the plots as this X variable is varied from its maximum value (top

plot) to the center value (middle plot) to its minimum value (bottom plot). Noted by a change in slope, the impact of the Range of the MV-22 is directly affected. When the Distance is high, more tonnage is delivered when the Range of the MV-22 is high. When the distance is low, more tonnage is delivered when the Range of the MV-22 is low. These observations agree with the explanation from the previous Interaction Plot. As a third affirmation, these clarifications could also have been derived from the resulting equations discussed earlier. An example using a spreadsheet to calculate the resulting equations will be discussed later in this section. In contrast, the impact of changing the Lift of the MV-22 remains constant.
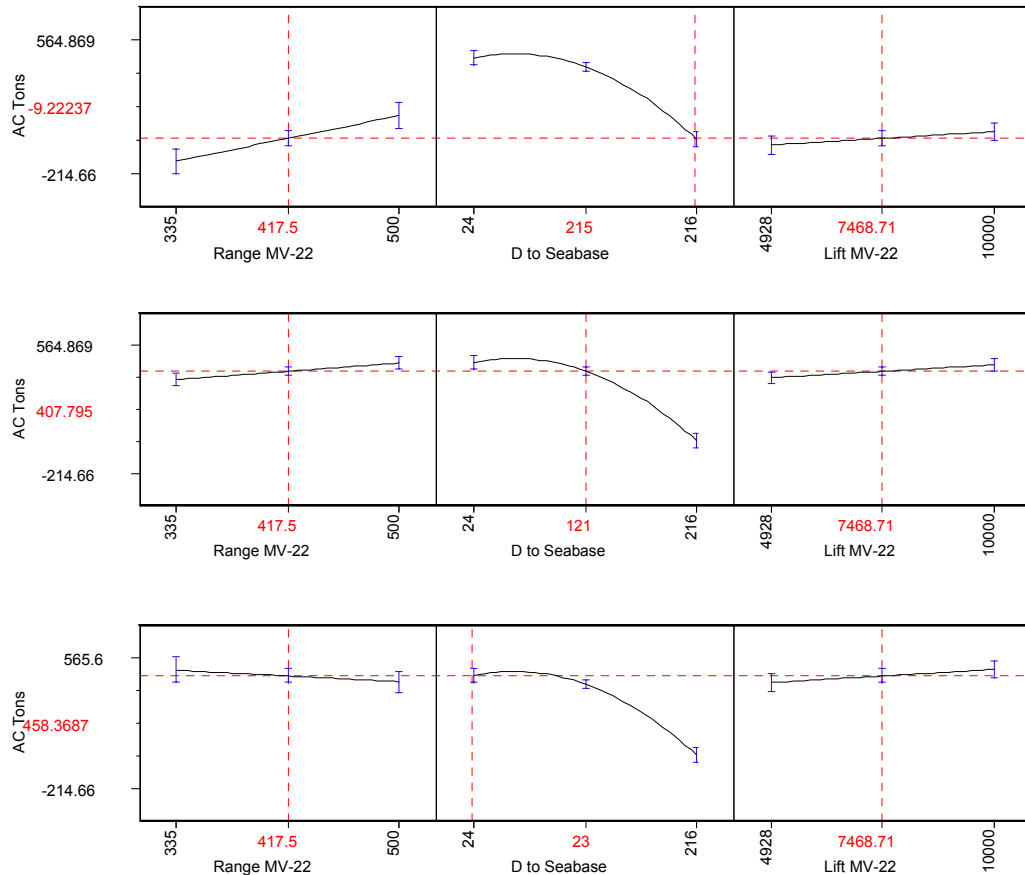
Figure 11.   Aircraft Tons Prediction Profiler

For the second MOE, Total Aircraft Sorties, the Interaction Plot in Figure 12 shows there are interactions between the Range of the MV-22 and the Distance to the Seabase main effects. Looking at the first row, fourth column, the effect of Spot Re-use is smaller at the lower capacities of the Lift of the MV-22, but it diverges for the upper capacities of the Lift of the MV-22. Additionally, you can visually see that the Range of the MV-22 has the most interactions (three) as seen by its row and column comparisons.

Figure 12.   Aircraft Sorties Interaction Plots

Since the Distance to the Seabase was a common factor across all three MOEs, the following Figure 13, displays the plots as this X variable is varied from its maximum (top plot) value to the center value (middle plot) to its minimum value (bottom plot). Noted by the change in slope for the Total Aircraft Sorties MOE, the impact of the Range of the MV-22 is directly affected, while the others were not affected.
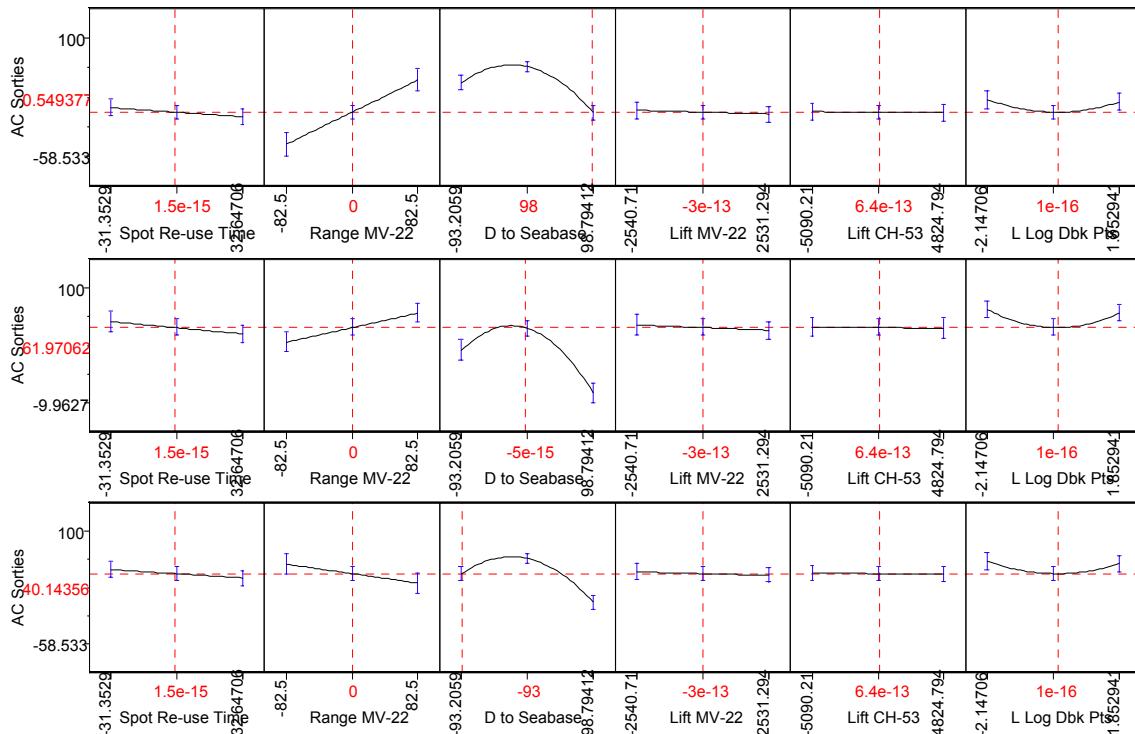
Figure 13.   Aircraft Sorties Prediction Profile

For the third MOE, the Interaction Plot in Figure 14 shows there are interactions among five of the main effects (solid lines). Looking at the first row, third column, the effect of Distance to the Seabase is smaller at the higher capacities of the Lift of the MV-22, but it diverges for the lower capacities of the Lift of the MV-22. Additionally, you can visually see that the Lift of the CH-53 has the most interactions (two) as seen by its row and column comparisons.

40

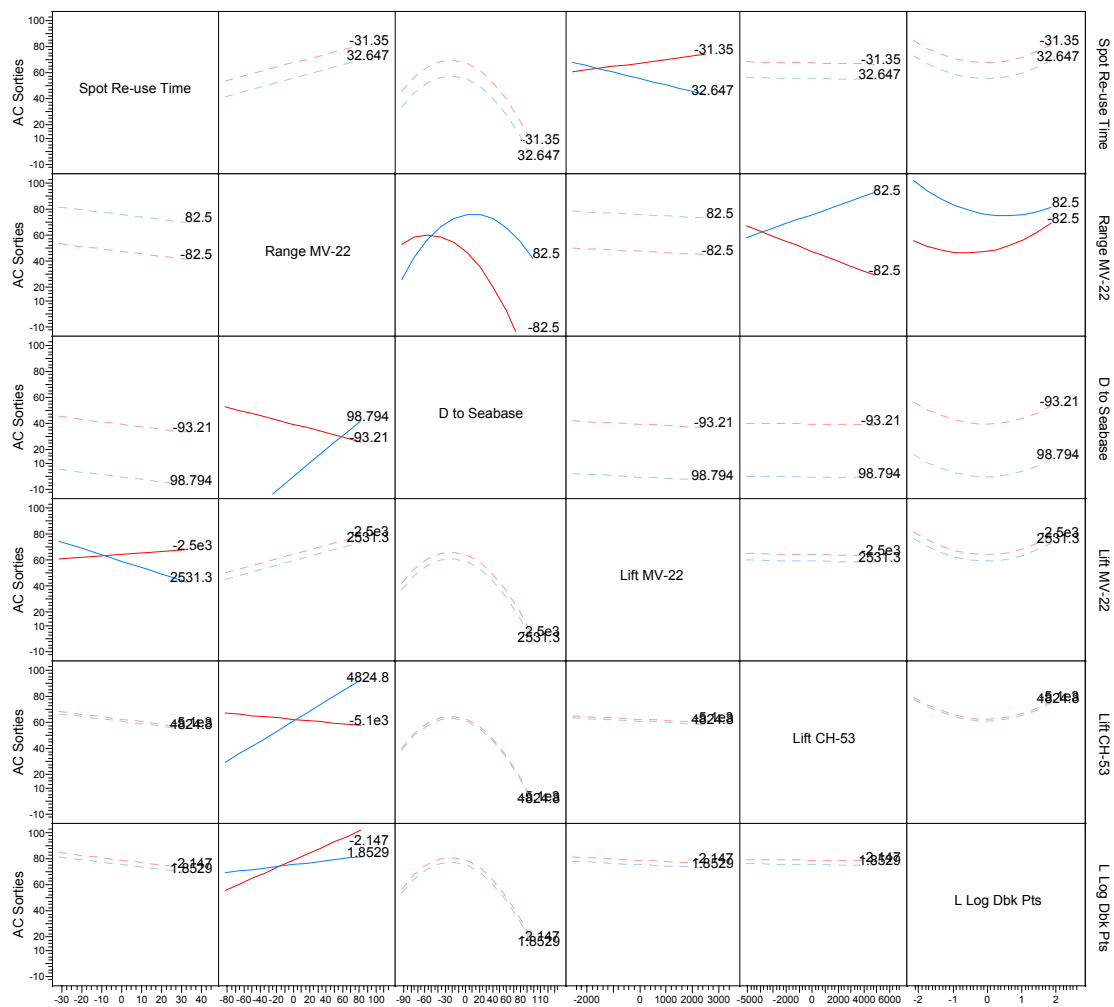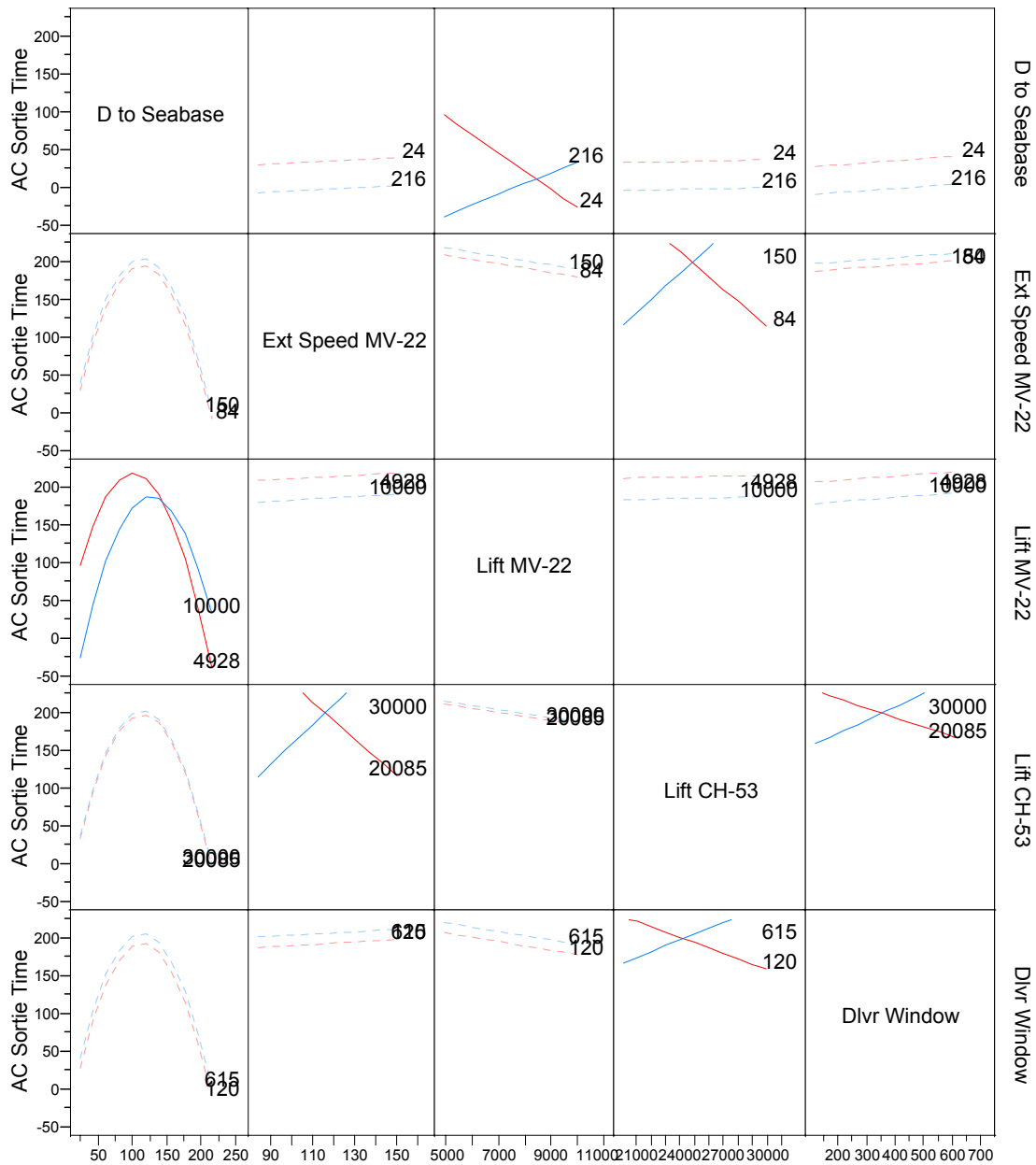Figure 14.   Aircraft Sortie Time – Interaction Plot

Since the Distance to the Seabase was a common factor across all three MOEs, the following Figure 15, displays the plots as this X variable is varied from its maximum (top plot) value to the center value (middle plot) to its minimum value (bottom plot). Noted by the change in slope, the Lift of the MV-22 is directly affected, while the others were not.
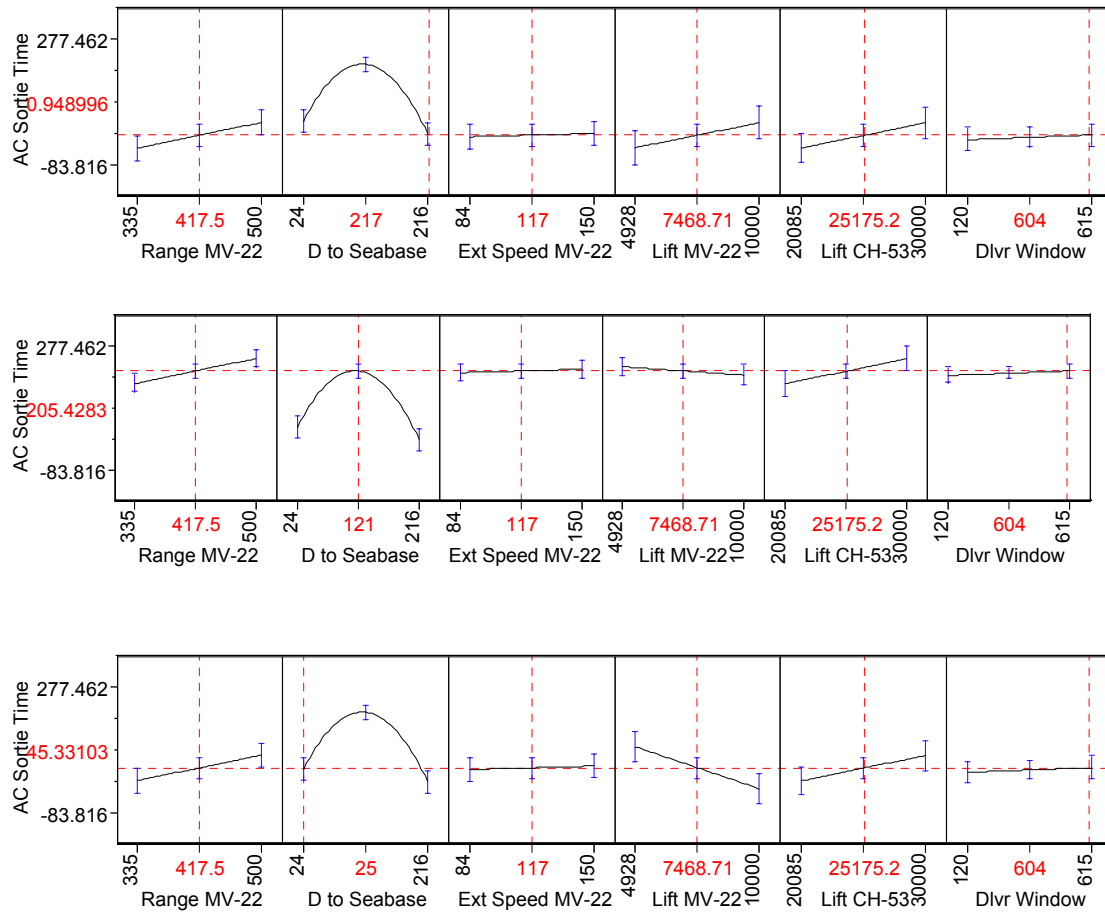
Figure 15.   Aircraft Sortie Time – Prediction Profile

As we discussed in Section 3.B.8, an accepted method of verifying the assumptions of regression analysis is to review graphical output from the fitted model. The most common plots are the "actual vs. predicted" and "residuals vs. predicted". Ideally, the actual vs. predicted plot will show linearity where all points fall along a diagonal line. The residual vs. predicted plot should show even distribution with no apparent pattern. We now present and discuss the plots corresponding to the Final Models for our three MOEs.

By viewing the output graphs from the Final Model for each measure of effectiveness, we can get a better idea of how well the predicted followed the actual measure of effectiveness. For the Total Aircraft Sorties plot in Figure 16, it appears as if all points are reflected along the positively sloped diagonal axis, indicating the predicted

and actual are related. Since the confidence curve (3 bands) crosses the horizontal sample mean, this implies the model is significant. The plot also shows the average Total Aircraft Sorties is approximately 54 sorties.

Figure 16.   Actual vs. Predicted Plot – Total Aircraft Sorties

By viewing the output graph of the residuals in Figure 17, we see that the residuals are evenly dispersed about the mean with no apparent pattern. This validates the assumption of identically distributed errors with a mean of zero and constant variance.
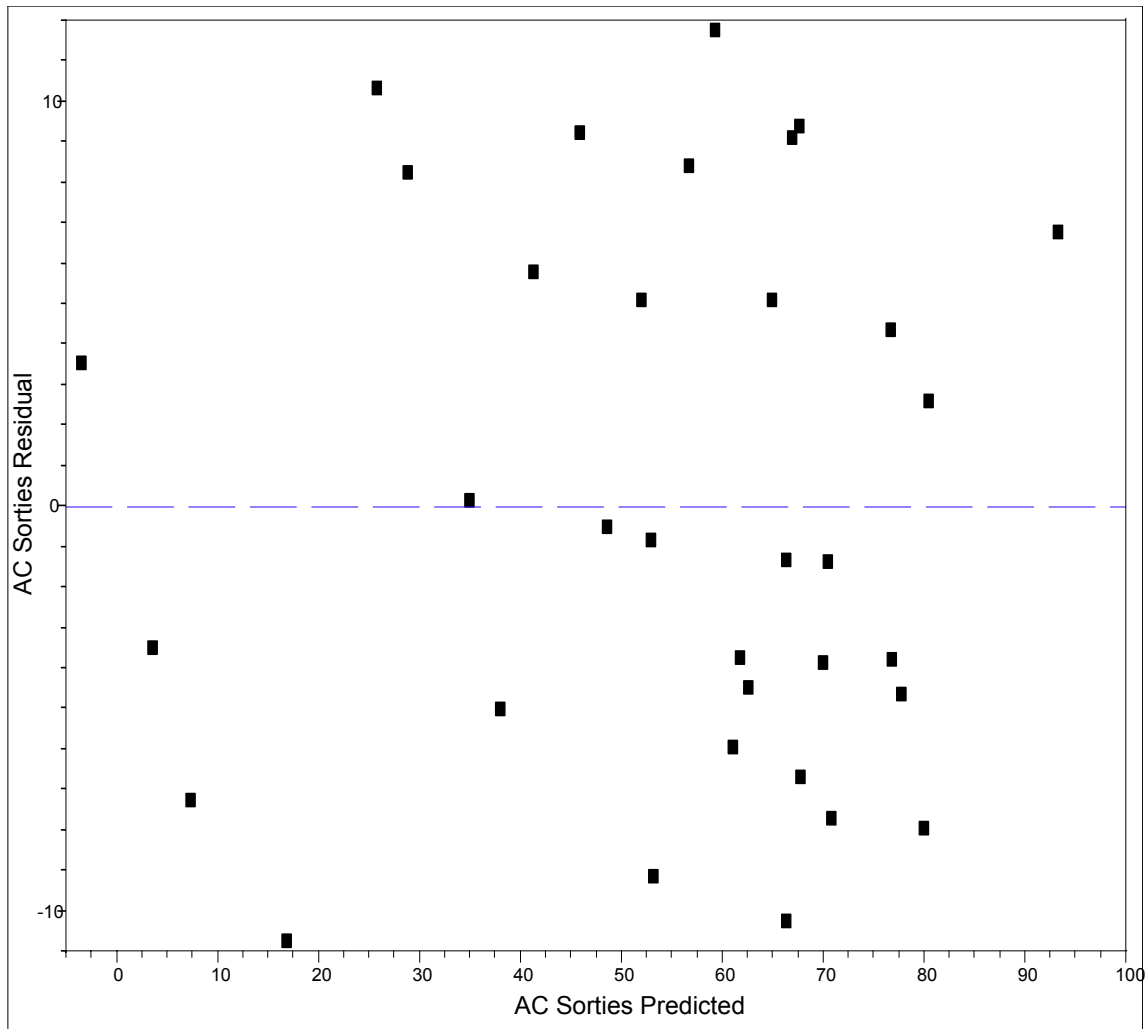
Figure 17.   Residual vs. Predicted Plot – Total Aircraft Sorties

For the Total Aircraft Tons plot in Figure 18, it appears as if most of the points are reflected along the positively sloped diagonal axis, indicating the predicted and actual points are relative. There does appear to be one outlier, number twelve, which relates to run eleven where there were zero tons delivered by the CH-53's but a small amount, 17.09 short tons (stons) was delivered by the MV-22's. Further research indicates the points that are circled and appear to be linearly related to each other, resulted in the same total of Aircraft Tons, despite there being different combination of tons carried by either the MV-22 or the CH-53. Since the confidence curve (3 bands) crosses the horizontal

sample mean, this implies the model is significant. Additionally, the plot also shows the average Total Aircraft Tons is approximately 345 stons.
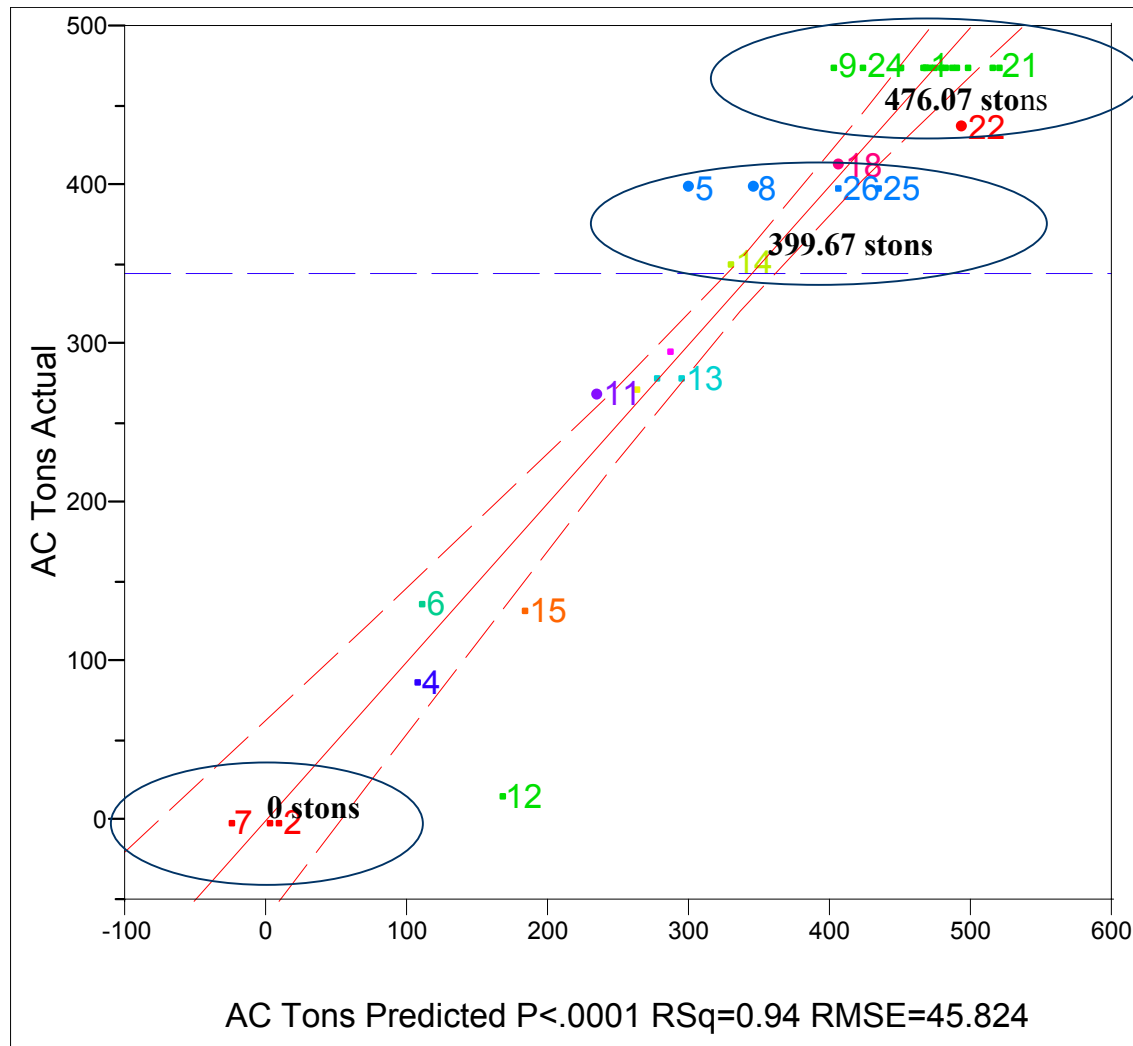
Figure 18.   Actual vs. Predicted – Total Aircraft Tons

By viewing the output graph of the residuals in Figure 19, we see that the residuals also appear to be dispersed about the mean with the only apparent pattern being a "diagonal" line intersecting the mean. This corresponds to the horizontal groupings seen on the Actual vs. Predicted plot where Total Aircraft Tons was equal across several runs. The lack of any other pattern means the regression assumption identically distributed errors with a mean of zero and constant variance is reasonable.
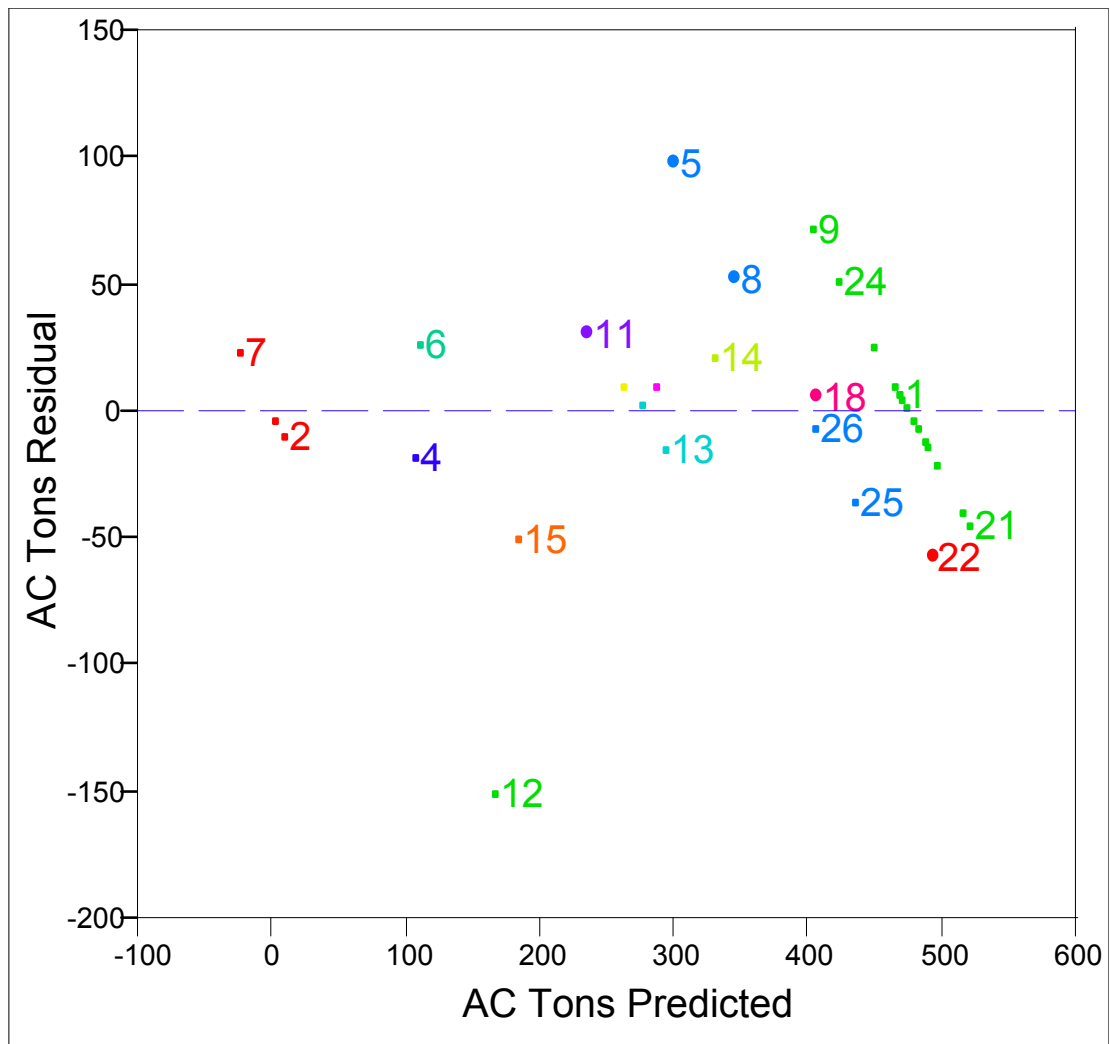
Figure 19.   Residual vs. Predicted – Total Aircraft Tons

For the Total Aircraft Sorties plot in Figure 20, it once again appears as if all points are reflected along the positively sloped diagonal axis, indicating the predicted and actual comply. Since the confidence curve (3 bands) crosses the horizontal sample mean, this implies the model is significant. The plot also shows the average Total Aircraft Sortie Time is approximately 130 hours.
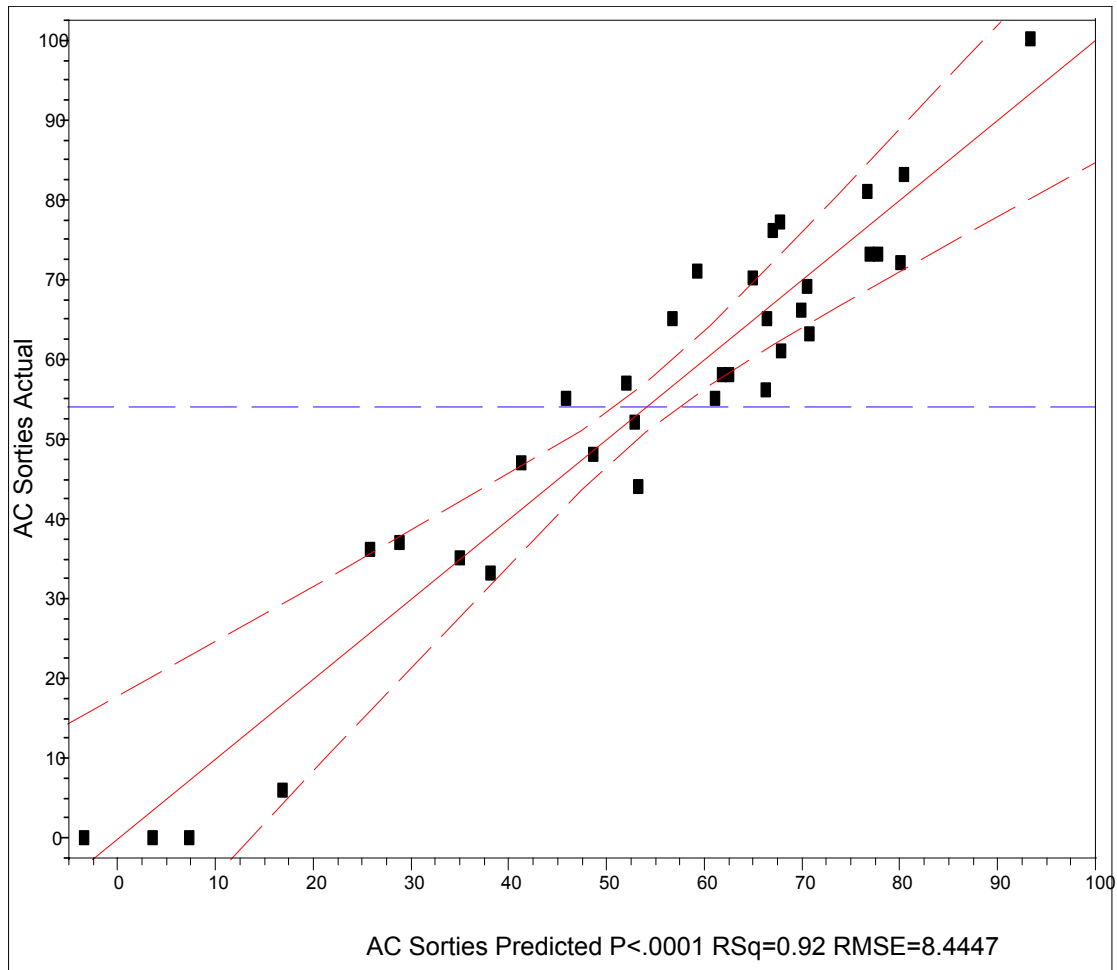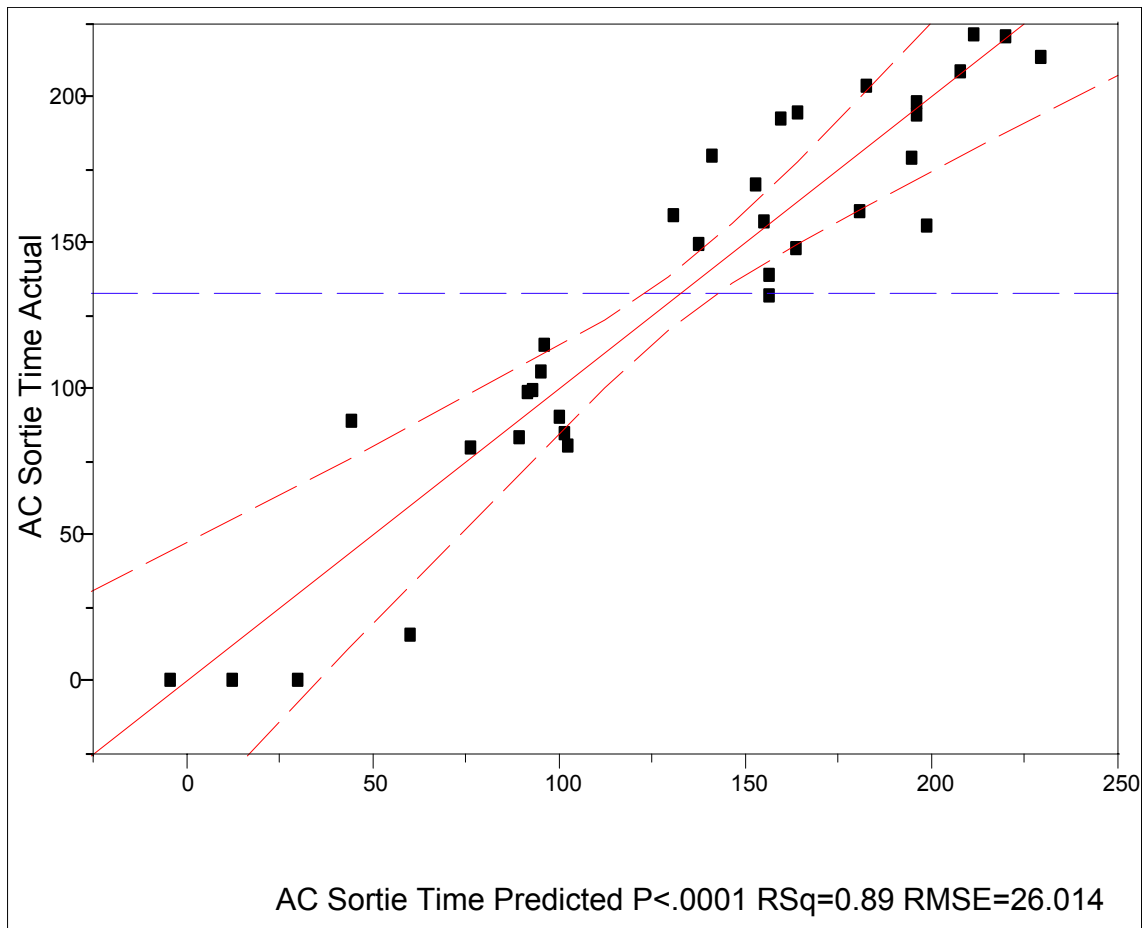
Figure 20.   Actual vs. Predicted – Total Aircraft Sortie Time

By viewing the output graph of the residuals in Figure 21, the residuals were dispersed about the mean with no apparent pattern. The lack of any other pattern means the regression assumption of identically distributed errors with a mean of zero and constant variance is reasonable.
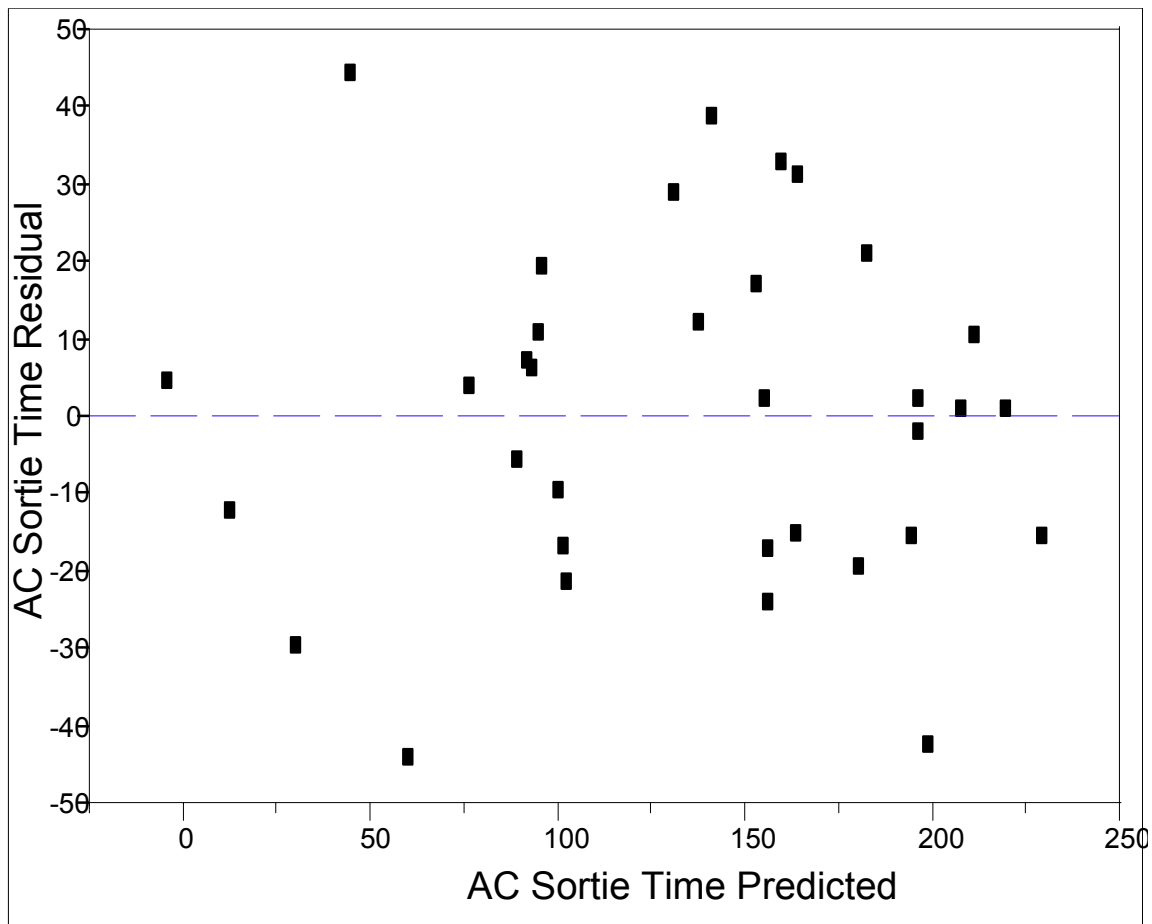
Figure 21.   Residual vs. Predicted – Total Aircraft Sortie Time

As a review, once the coefficient estimates beta have been estimated, predicted values for all chosen MOEs can be generated using a spreadsheet such as Microsoft Excel® in a fraction of second. Figure 22 gives a general example of how to lay out the rows and columns in order to facilitate predicting the chosen MOEs. The example shown displays the factors set to their baseline case values. Slider bars above the value facilitate the varying of the factors through their respective ranges. The values in the "predicted" row are a result of the Final Model equations for each MOE. For comparison purposes, the predicted and actual values for the baseline experiment were 385.45 and 476.07 stons for Total Aircraft Tons, 52.36 and 57 for the number of Total Aircraft Sorties, and 71.64 and 80.48 hours for Total Aircraft Sortie Time.

	A	B	C	D	E	F	G	
					Total Aircraft Tons	Total Aircraft Sorties	Total Aircraft Sortie Time	
1	Baseline Scenario Example							
2					385.45091	52.35922	71.63878	
3			Range					
4		Min	Max					
5	Spot Re-use Time	20	84	30				
6	Range of MV-22	335	500	500				
7	Range of CH53	235	395	400				
8	Distance to Seabase	24	216	25				
9	External Speed CH-53	44	110	110				
10	External Speed MV-22	84	150	150				
11	Lift of MV-22	4928	10000	10000				
12	Lift of CH-53	20085	30000	30000				
13	Delivery Window	120	615	360				
14	MPF(F) log Dbk Pts	1	6	5				
15	L-Log Dbk Pts	1	5	4				

Figure 22.   Excel Spreadsheet Example of Final Model Equations

49

THIS PAGE INTENTIONALLY LEFT BLANK

IV.   CONCLUSIONS AND RECOMMENDATIONS

Seabasing involves providing versatile seabased platforms in order to project US forces ashore in areas of the world where land-based options are not available. This concept has been around for a long time, but is currently becoming recognized as an important requirement. A seabase could be a single platform, or a group of high-speed, high-volume, and air capable platforms. Seabasing is not a thing or a platform, but an aggregation of capabilities composed of command and control, defensive and offensive capabilities as well as logistics. Seabasing is the "whole package" (Waterline 2003).

In this thesis, we used a currently fielded program SEAWAY to evaluate a seabase scenario. The scenario conducted was an amphibious operation on the Korean peninsula using the 2015 MEB. The seabase scenario focused on utilizing the same one phase scheme of maneuver (SOM) using different vertical lift asset mixes covering a varying seabase to objective landing zone distance. Based on the scenario, the following measures of effectiveness (MOEs) were chosen: Total Number of Aircraft Sorties, Total Aircraft Sortie Time, and Total Aircraft Tons Delivered.

Data farming techniques were applied to the SEAWAY agent based software in order to explore the program's behavior. The technique used was a Latin Hypercube (LHC) design sampling technique where all portions of the distribution of the range of a factor are divided into equal increments. The general methodology used to collect and analyze the data was to select the factors related to our MOEs, apply the LHC design, and to use multiple regression models to fit the resulting datasets in order to identify significant factor combinations. Our research found that for three stated measures of effectiveness, we were able to determine that specified factors were capable of explaining most of the variation in the MOEs.

In the course of doing this study, the importance of the results of the model, data farming techniques and agent-based models became readily apparent. The findings and recommendations within each of these subject areas are worth reviewing. The following three subject areas discuss in greater detail our observations. As this research evolved,

other questions regarding seabasing logistics transpired. The specific SEAWAY and seabasing related questions follow as an invitation for future thesis students interested in seabasing logistics.

A. FINAL MODEL RESULTS

1. Conclusions

As a result of fitting four models, this study uncovered three main aspects. First, the seabasing environment modeled was found to be effectively described by a few factor combinations. Second, interactions between parameters provided additional explanatory reasoning. Third, it was surprising to find the final models captured a large percentage of the variability with four similar terms, three main effects and one quadratic term, across the four models.

The "back of the envelope" methodology that resulted from this research will provide the logistician in the field an extremely fast "ball park" figure prior to them getting more detailed plans from running the SEAWAY program. Across the three MOEs analyzed in this research, we found there were four specific terms that were most significant. These four terms are the areas in which the logistician should focus on to bring the logistics plan back into swing or the four terms that when the SOM is not going along as planned, they will have the greatest variation or impact on the resulting Air and Surface Delivery Plan.

This parsimonious model will provide the time-crunched logistician a 'fast and furious' methodology for identifying significant factors to modify that will be more likely to provide an acceptable Air and Surface Delivery Plan. A spreadsheet program like Microsoft Excel ® can be used to employ the resulting equations easily. This spreadsheet tool is a great complement to the SEAWAY program, especially when time constraints do not allow for running of the SEAWAY program multiple times.

2. Recommendations

The results of this research should be used in conjunction with the execution of the SEAWAY program. The ability to use a prediction equation with the coefficient estimates beta and the five significant factors as variables can generate predicted values for a chosen MOE in a fraction of second. This is a huge time advantage for the

logistician decision maker in the field since the SEAWAY program takes at least two hours to run. Without the aid of this research, any alterations to an unacceptable Air and Surface Delivery Plan will be at the discretion of the logistician who may or may not have little or no guidance on how to get improvement. The amount of time saved by minimizing the number of times the SEAWAY program executes is priceless in an unpredictable combat environment. The logistician can now use his new decision making skills to adjust aspects of the plan based on the factors they know will have the largest impact on successful MOEs. Additionally, they also have a better idea of what areas can remain unchanged because of their proven lack of significance.

Before beginning the analysis, it would behoove the analyst to become familiar with a statistical software package that offers a broad range of graphical and statistical methods for data analysis. Although this research used a combination of JMP and Microsoft Excel ®, there are many other statistical software packages on the market.

While this research focused on vertical lift assets, analysis of this scenario could have focused on naval support assets or any other logistics aspect of a seabasing scenario. SEAWAY reports provide a large number of data points that are easily exportable into a spreadsheet. It is up to the analyst to determine what logistical aspect they wish to study.

During the fitting of the models, the analyst was required to do a sanity check on each of the models verifying that the factors left over after being added during the step-wise analysis made sense when related to the given set of measures of effectiveness. This proved to be a trial and error process. In order to circumvent this issue, one should continually pose questions during the stepwise process in order to ensure that no term is overlooked regarding its relevance to the given MOE. The automated procedures can be helpful but are not a substitute for the analysts' judgment.

B. DATA FARMING AND DESIGN OF EXPERIMENTS

1. Conclusions

Complex scenarios such as the seabasing Logistics problem include many variables and/or multifaceted interactions. In order to identify which factors pose the greatest effect on the given measures of effectiveness, data farming with the aid of a

design of experiments provides useful tools for the analyst. This study considered seventy-seven term combinations at thirty-three different design points.

Since SEAWAY is a stand-alone system, computing power was limited to the system requirements of the laptop computer. The ability to generate data when fine-tuning the design runs, or during analysis of results, was limited by computer system requirements. In order to work within the system's limitations, the LHC design was extremely useful in ensuring each parameter was tested over the ranges selected. This contributed to the resulting "back of the envelope" structured sound analysis.

2. Recommendations

When analyzing a complex real world problem with many factors, the data farming procedure used in this study is useful. Although the SEAWAY program is not currently set up to analyze scenarios in a "super computing" environment, the developers are working on a "batch process" input feature which will minimize any errors caused by manually varying input parameters. Since SEAWAY is not capable of batch processing at the time of this research, the author was resigned to input and vary each run's factors manually. This feature is critical if SEAWAY is to be used not only by the field user but by analysts working on developing improvements to the program itself.

The use of a LHC design was extremely useful in assisting the set-up of determining model factors. Since there are no restrictions on the number of factors in the design, this process could be very useful for exploring scenarios that are more complex.

C. AGENT BASED MODELS

1. Conclusions

Agent-based models allow the analyst to create and simulate a complex real world scenario. The ability for agent-based models to include the capability to measure and transfer the use of supply resources is a limited potential amongst the agent-based programs used by the Department of Defense. One program developed with this precise capability is the SEAWAY program developed by CDM Technologies Inc. Since SEAWAY is a relatively new decision making tool, its capability to assist in seabase operations will play an integral role in the naval and joint seabase logistics programs in support of Sea Power 21.

In general, when coming up with a scenario that may be solved in an agent- based environment, the analyst may be required to be creative in their manipulation and interpretation of necessary factors. Initially, the author had investigated using Pythagoras and Socrates agent-based programs to create a seabase logistics scenario. However, the level of creativity needed to simulate replenishment of supply resources proved to be too labor intensive. With technological improvements and more research time it is possible for Pythagoras and Socrates agent-based programs to support any logistics based scenarios.

2. Recommendations

Despite the success of the results of this analysis, there were some difficulties associated with running the SEAWAY program. The GUI interface, although useful for the field user, was an impediment of time when running the program multiple times. Common errors include "fat finger" syndrome and miscalculations of measured units.

In spite of the above-mentioned shortcomings of the SEAWAY program, it is still an excellent tool for the field user to come up with an Air and Surface Delivery Plan capable of supporting a variety of scheme of maneuvers (SOM) relative to world events. This research has provided a "back of the envelope" solution in how to alter the plan's inputs (factors) in order to come up with an acceptable plan in a fraction of a second. This "back of the envelope" solution can then be used in conjunction with the SEAWAY program to provide the field user options as to which inputs have the most predictable power, thereby saving program run time for an ideal Air and Surface Delivery plan supporting a specific SOM or COA.

D. RECOMMENDATIONS FOR FUTURE RESEARCH

As the OPNAV N7 and CDM Technologies Seabasing Assessment concluded and this research evolved, a number of related questions surfaced and could prove to be worthwhile thesis research for other interested students. The SEAWAY program as well as any other agent-based program with creative manipulation, could be used to answer any of the following questions:

1.   SEAWAY Related Questions

A connector is a generic representation of any small transportation device on the seabase that is lifting personnel, fuel, or cargo. Some examples of this are LCACs, LCU, CH-46, CH-53, MV-22, High Speed Connector (HSC), LCAC(X), LCH(X).   On the other hand, a prime mover is a generic representation of any large transportation device on the seabase that is lifting personnel, fuel, or cargo. Some examples include LHD, LPD, LSD, MPF, MPF(F), or other MSC or CLF ship.

- Is there a correlation between the available logistics connectors and other related factors in order to maximize efficiency and queuing? (Other related factors include debarkation points, transit lanes, landing zones, loading/unloading of cargo and the amount of cargo (in short tons) carried by a connector);

- If some of the variables are known, is there an appropriate equation to assist in the determination of time efficiency?

- If I know the number of debarkation spots, transit lanes, landing zones, loading and offloading times, the amount of cargo to be delivered, and asset capacity, then how many connectors must be available in order to deliver the cargo within a specified amount of time in order to minimize or eliminate queuing?

- For Integrated Naval Logistics packaging, is there a commercially viable way of delivering re-supply from the seabase using a combination of commercial black hulls, military gray hulls, and surface and vertical connectors to allow for the eventual delivery of tailored supply packages?

- What if commercial sources maximize the use of twenty-foot equivalent units (TEU) for bulk delivery and ground units require tailored re-supply packages for reception. Is the best solution using a new method of packaging and delivery? What would it look like?

- Alternatively, is the best solution a new system that breaks down the TEU and repackages the cargo for follow-on tailored delivery? What would be the

transfer, strike-up/strike-down, the automated cargo handling, and the tailored repackaging requirements for MPF(F), Large Medium Roll-On/Roll-Off (LMSR), and amphibious ships (L-class) in order to support this method of logistics transfer?

The biggest technology gap identified to date for seabasing is the interface requirement for large and small vessels for conducting rolling stock material transfer on the seabase through sea state four.

- What are the interfaces required between large hulls and between large and small hulls when transferring personnel, equipment, and cargo for follow-on transfer ashore?

- Is there a generic interface that could be developed for all types of vessels or is the only solution a point solution for each type of interface?

Consider a notional seabased force consisting of six MPF(F) ships, two ESG's, and two CSG's with their accompanying aircraft (seventy-two MV-22, twenty-eight CH-53, twenty-four LCAC (SLEP) equivalent, and three LCU(R)).

- If the daily MEB delivery requirement is 1030 short tons, what is the potential excess delivery capacity available from the seabase in support of joint operations?

2. Seabasing Related Questions

In a seabase scenario, the following areas provide good measures of effectiveness (MOEs): mission criticalities, readiness, efficiency, effectiveness, size of footprint, integrated load outs, adaptability and robustness, and asset visibility.

- How, and using what criteria, do we measure the effectiveness and efficiency of a proposed ship's capability to support seabase operations?

- How do we plan and coordinate the logistical support from the seabase to the forces ashore?

- How can we exploit seabase assets?

- What re-supply processes work best for combat, training, peacekeeping or humanitarian assistance/disaster recovery scenarios?

- Using current and future assets of a seabase scenario, how does the selection of ships affect transport, cargo, and the capability to support forces ashore?

E.   SYNOPSIS

As Lieutenant General Hanlon, the Deputy Commandant Combat Development said in a recent address before the Committee on Armed Services (Hanlon, 2004):

> In Operation Enduring Freedom, sea-based Marines projected power hundreds of miles inland to establish a stronghold deep in enemy territory. During Operation Iraqi Freedom, more than 66,000 Marines (including Reservists), their equipment, and supplies deployed to the Iraqi theater using a combination of expeditionary amphibious warships comprising two Amphibious Task Forces, two Maritime Prepositioning Squadrons (MPS), and strategic military and chartered commercial airlift. Once combat commenced, a Marine Corps combined-arms team advanced more than 450 miles from the sea to Baghdad and beyond. Your Marine Corps went farther, faster than in any time in its history, and achieved successes in every battle.

It is clear that seabased logistics is a bold move toward a fully integrated warfighting capability that will take the military forces into the 21st century.

APPENDIX

A. Design of Experiments Ordinary Latin Hypercube Matrix

	A	B	C	D	E	F	G	H	I	J	K	L
	Run	Distance to Seabase	External Speed MV-22	External speed CH-53	Lift Capacity MV-22	Lift Capacity of CH-53	Delivery Window	Spot re-use, after take-off	Range of MV-22	Range of CH-53	MPF(F) Logistics Debark Pts per ship	L-Class Logistics Debark Pts per ship
2	Max	216	148	108	9856	29973	615	84	495	395	6	5
3	Min	24	84	44	4928	20085	120	20	335	235	1	1
4	Incr	6	2	2	150	300	15	2	5	5	1	1
5	Levels	33	33	33	33	33	33	33	33	33	6	5
6												
7												
8	1	216	90	72	7238	21939	555	64	435	395	4	4
9	2	198	148	52	6468	23793	360	48	365	380	5	4
10	3	192	112	102	5082	21630	135	82	430	285	2	4
11	4	132	140	108	5236	24102	585	26	360	305	2	5
12	5	204	86	74	7700	22248	465	28	450	245	4	3
13	6	210	144	64	9240	22866	345	54	370	240	4	1
14	7	156	114	106	9394	22557	120	20	440	375	2	2
15	8	126	128	104	9856	23484	570	80	375	320	2	2
16	9	150	100	58	5852	25338	480	58	385	330	1	1
17	10	168	126	62	6776	26883	225	32	420	370	1	1
18	11	162	98	92	5698	29664	285	60	345	295	4	1
19	12	174	130	86	6930	29355	495	30	490	270	4	3
20	13	138	94	56	8778	25647	420	38	355	290	1	5
21	14	186	122	68	8470	28737	195	70	425	275	1	5
22	15	144	96	98	8624	29046	300	42	335	350	5	4
23	16	180	124	82	8162	29973	525	68	480	365	3	4
24	17	120	116	76	7392	25029	375	52	415	315	3	3
25	18	24	142	80	7546	28119	180	40	395	235	3	2
26	19	42	84	100	8316	26265	390	56	465	250	1	2
27	20	48	120	50	9702	28428	600	22	400	345	4	2
28	21	108	92	44	9548	25956	150	78	470	325	5	2
29	22	36	146	78	7084	27810	270	76	380	385	2	4
30	23	30	88	88	5544	27192	405	50	460	390	2	5
31	24	84	118	46	5390	27501	615	84	390	255	4	4
32	25	114	104	48	4928	26574	165	24	455	310	5	5
33	26	90	132	94	8932	24720	255	46	445	300	6	5
34	27	72	106	90	8008	23175	510	72	410	260	6	5
35	28	78	134	60	9086	20394	450	44	485	335	2	5
36	29	66	102	66	7854	20703	240	74	340	360	3	3
37	30	102	138	96	6006	24411	330	66	475	340	6	1
38	31	54	110	84	6314	21321	540	34	405	355	5	1
39	32	96	136	54	6160	21012	435	62	495	280	1	2
40	33	60	108	70	6622	20085	210	36	350	265	3	3

Figure 23.   Design Factors in Ordinary Latin Hypercube Matrix

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Battaglini, J. R. and K. J. Glueck. 2003. *Seabasing CONOPS (draft).* July.

Becker, M. 2003. Re: SEAWAY Scenario. October. Available e-mail from: mark.becker@navy.mil

Brown, L. P. 2000. Agent Based Simulation as an Exploratory Tool in the Study of Human Dimension. Master's thesis in Operations Research, Naval Postgraduate School, Monterey CA. Available online at http://library.nps.navy.mil/uhtbin/hyperion-image/00_Brown.pdf (accessed January 2004).

Bryan, K. H. and K. Kang and G. Ameyugo. 2002. *An Analysis of Ship to Objective Maneuver (STOM) in Seabased Logistics*. Available online at: http://informs-cs/wsc02papers/118.pdf (accessed January 2004)

Castelli, C. J. 2002. *Navy May Develop New Support Ships, Pursue Sealift Experimentation,* Inside the Navy, pg. 1, May.

CDM Technologies, Inc. "SEAWAY: Joint Decision-Support System for Sea Base Logistics Planning and Coordination". Available online at: http://www.cadrc.calpoly.edu/pdf/Seaway_Brochure.pdf (accessed September 2003)

CDM Technologies, Inc. 2002. "Seaway-Loggy: An Agent-Based Adaptive C2 Tool for the JTF and MAGTF". December.

CDM Technologies, Inc. 2002. "CDM Vice President presents SEAWAY at Conference on Expeditionary Warfare".

CDM Technologies, Inc. March 2003. "SEAWAY-Version 2.0 Commander's Overview".

CDM Technologies, Inc. Powerpoint presentation: SEAWAY: Adaptive Command and Control for Naval Expeditionary logistics. Available online at: http://www.dtic.mil/ndia/ewc/Wood.pdf (accessed March 2004)

Chase, C. 2004. USMC School of MAGTF Logistics Information Paper: SEAWAY. January. Available online at: http://www.wargaming.quantico.usmc.mil/Documents/Seaway%20Info%20Paper.pdf (accessed March 2004)

Clancey, Patrick. 2004. *Ships of the U.S. Navy, 1940-1945* web pages. Available online at: http://www.ibiblio.org/hyperwar/usn/usn-ships (accessed March 2004)

Clark, V. 2002. *Projecting Decisive Joint Capabilities.* October. Available online at: http://www.usni.org/Proceedings/Articles02/proCNO10.htm (accessed October 2003)

Cioppa, T. M. 2002. *Efficient Nearly Orthogonal and Space-Filling Experimental Designs for High-Dimensional Complex Models*. Doctoral thesis in Operations Research, Naval Postgraduate School, Monterey, CA.

Cioppa, T. M. 2003. *Advanced Experimental Designs for Military Simulations.* U. S. Army Training Doctrination Analysis Center. Monterey, CA.

Corbett, A. and V. Goulding. 2002. *Sea Basing: What's New?*, Naval Institute Proceedings, November. Available online at: http://www.usni.org/Proceedings/Articles02/PROcorbett11.htm (accessed October 2003)

Devore, Jay l., *Probability and Statistics for Engineering and the Sciences*, 5th Edition, Duxbury Press, 2000.

Global Security web pages. Available online at: http://www.globalsecurity.org/militarysystems/ship/lhx.htm (accessed March 2004)

Hagee, M. W., 2004. Message to the fleet, dtg: 020800ZFEB04.

Hamilton, Lawrence C., *Regression with Graphics: A Second Course in Applied Statistics*, Duxbury Press, 1992.

Hanlon, E. Jr. 2004. Statement before the committee on Armed Services Sub-committee on Terrorism, Unconventional Threats and Capabilities. February.

Horne, G. and M. Leonardi. eds. 2001. *Maneuver Warfare Science 2001.* Marine Corps Combat Development Command, Quantico, VA.

Horne, G. and S. Johnson. eds. 2002. *Maneuver Warfare Science 2002.* USMC Project Albert, Quantico, VA.

Horne, G. and S. Johnson. eds. 2003. *Maneuver Warfare Science 2003.* USMC Project Albert, Quantico, VA.

JMP® Statistics and Graphics Guide, Version 5, SAS Institute Inc., 2002.

Kleijnen, J.P.C., S. M. Sanchez, T. W. Lucas, and T. M. Cioppa. 2004. "A user's guide to the brave new world of designing simulation experiments." Working paper, Tilburg University.

Koch, A. 2002. *USA Looks To Enhance Sea-Basing Capabilities,* Jane's Defence Weekly, May.

Krulak, C. 1999. *Operational Manuever from the Sea.* Joint Forces Quarterly.

L-3 Communications Analytics Corp. 2003. *SOCRATES v3.2.4 Analyst's & User Manuals,* Arlington, VA. September.

Lucas, T. W., S. M. Sanchez, L. Brown, W. Vinyard. 2002. Better Designs for high-dimensional explorations of distillations. G. Horne, S. Johnson eds. *Maneuver Warfare Science 2002*. USMC Project Albert, Quantico, VA. 17-46.

Marine Corps Doctrinal Publication (MCDP) – 4. 1997 *Logistics*. Headquarters, U.S. Marine Corps. Washington, D.C. February.

Marine Aviation Weapons Tactics Squadron One (MAWTS-1). 2000. *A MEB in 2010, An analysis of Operational Potential and Logistics capabilities*. Marine Corps Air Station (MCAS) Yuma, AZ. May.

Marine Corps Warfighting Laboratory (MCWL), Project Albert web pages. Available online at:
http://www.mcwl.quantico.usmc.mil/divisions/albert/index.asp (accessed January 2004)

Military Analysis Network. *Seabase* Available online at:
http://www.fas.org/man/dod-101/sys/ship/seabase.htm (accessed November 2003)

Military Sealift Command (MSC) web pages. Available online at:
http://www.msc.navy.mil/inventory/ships.asp (accessed March 2004)

Moore, C. W. and E. Hanlon Jr. 2003 *Sea Basing: Operational Independence for a New Century, Proceedings.* January .

Naval Operating Concept (NOC) for Joint Operations, signed by Chief of Naval Operations and Commandant of the Marine Corps, date unknown.

Nagy, P. 2002 *The History of Sea Basing,* Naval Institute Proceedings, November. http://www.usni.org/Proceedings/Articles02/PROcorbett11.htm

Naval Warfare Development Command, *Seabasing*, Available online at: http://www.nwdc.navy.mil/Concepts/SeaBasing.asp (accessed Novemeber 2003)

Northrup Grumman Corporation. 2003 *Pythagoras Manual: Version 1.6.3.* Arlington, VA.

Office of the Chief of Naval Operations (CNO) Expeditionary Warfare, N75 web pages. Available online at: http://www.exwar.org/htm/5000PopD3.htm (accessed March 2004)

OPNAV N703G, CDM Technologies. 2003. Seabasing Assessment Working Paper.

Rhodes, J. E. and G. S. Holder. 1998. *Seabased Logistics: A 21st century warfighting concept*, Marine Corps Development Command and Navy Doctrine Command. May.

Rowland, S. C. *Powerpoint Brief: Sea Basing Capabilities,* http://www.onr.navy.mil/sci_tech/special/353_exped/docs/sb/n75.ppt (accessed January 2004)

Sanchez, S. M., T. W. Lucas. 2002. Exploring the world of agent-based simulations: simple models, complex analyses. E. Yucesan, C.-H. Chen, J. L. Snowden, J. Charnes, eds. *Proceedings of the 2002 Winter Simulation Conference*, Institute of Electrical and Electronics Engineers, Piscataway, NJ. 116-126.

Stephen, R. T., M. A. Anderson, and M. K. Lauren. 2002. MANA Map Aware Non-uniform Automata Version 2.0 User's Manual. Defence Technology Agency, Devonport Naval Base, Auckland, New Zealand.

USMC Warfighting Lab web pages. "Seaway/Loggy Programs". Available online at: http://www.wargaming.quantico.usmc.mil/Programs/SeawayLoggy.cfm, (accessed October 2003)

Seabasing: Assured Access and Power Projection from the Sea, Expeditionary Force Development Center, Quantico, VA; CD, date unknown.

Wolf, E. S. 2003. Using agent-based distillations to explore logistics support to urban, humanitarian assistance/disaster relief operations. Master's thesis in Operations Research, Naval Postgraduate School, Monterey, CA Available online at http://library.nps.navy.mil/uhtbin/hyperion-image/03Sep%5Wolf.pdf (accessed November 2003)

Wolf, E. S., S. M. Sanchez, N. Goerger, L. Brown. 2003. Using agents to model logistics. Working Paper, Operations Research Department, Naval Postgraduate School, Monterey, CA.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS

ABD	Agent Based Distillations
ABM	Agent Based Models
ARG	Amphibious Ready Group
CAS	Complex Adaptive Systems
CFF	Calls for Fire
CIL	Critical Item List
CLF	Combat Logistics Force
CNO	Chief of Naval Operations
COA	Courses of Action
CSG	Carrier Strike Group
CSS	Combat Service Support
DOD	Department of Defense
DP	Delivery Plan
EMW	Expeditionary Maneuver Warfare
ESG	Expeditionary Strike Group
FARP	Forward Arming and Refueling Points
GB	Gigabyte
GHZ	Gigahertz
HIMARS	High Mobility Artillery Rocket System
HL-LCAC	Heavy Lift Landing Craft Air Cushion
HSC	High Speed Connector
HSV	High Speed Vessels
ILP	Integrated Logistics Platform
ISEP	Intermediate Staging and Embarkation Point
JSF	Joint Strike Fighter
LCAC	Landing Craft Air Cushion
LCAC(X)	Landing Craft Air Cushion Variant
LCH(X)	Landing Craft Hybrid Air Cushion Displacement
LCU	Littoral Craft Unit
LHC	Latin Hypercube
LMSR	Large Medium Speed Roll-on/Roll-off
LZ	Landing Zone
MAGTF	Marine Air-Ground Task Force
MB	Megabyte
MCCDC	Marine Corps Combat Development Command
MCWL	Marine Corps Warfighting Lab
MEB	Marine Expeditionary Brigade
MPF	Maritime Prepositioning Force
MPF(F)	Maritime Prepositioning Force (Future)
MSC	Military Sealift Command
NOC	Naval Operating Concept
OEF	Operation Enduring Freedom

OIF	Operation Iraqi Freedom
OLHC	Orthogonal Latin Hypercube
OMFTS	Operational Maneuver from the Sea
OPNAV	Office of Naval
OZ	Objective Zone
PA	Project Albert
RAM	Random Access Memory
SAG	Surface Action Group
SOLR	Statement of Logistics Requirements
SOM	Scheme of Maneuver
SPECOPS	Special Operations
STOM	Ship to Objective Maneuver
STONS	Short Tons
TCM	Tactical Control Measures
TEU	Twenty Foot Equivalent Unit
TRAC-M	Training Analysis and Doctrine Command (Analysis Center – Monterey)
TRADOC	Training Analysis and Doctrine Command
VTOL	Vertical Take-off and Landing

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
      Ft. Belvoir, Virginia

2. Dudley Knox Library
      Naval Postgraduate School
      Monterey, California

3. Mr. Anthony Wood
      SEAWAY Director
      San Luis Obispo, California

4. CDR Mark A. Becker
      OPNAV N703B
      Pentagon
      Washington, D.C.

5. Professor Susan M. Sanchez
      Department of Operations Research
      Naval Postgraduate School
      Monterey, California

6. Maj Lloyd Brown
      TRAC-Monterey
      Monterey, California

7. Professor David Schrady
      Department of Operations Research
      Naval Postgraduate School
      Monterey, California

8. Dr. Gary E. Horne
      Marine Corps Warfighting Lab
      Quantico, Virginia

9. Lieutenant Commander Rebecca M. Milton
      Assistant Supply Officer
      USS Peleliu (LHA-5)
      San Diego, California

THIS PAGE INTENTIONALLY LEFT BLANK